COMMONWEALTH OF THE NORTHERN MARIANA ISLANDS

Eloy S. Inos
Governor

Ralph DLG. Torres
Lieutenant Governor

01 OCT 2015

Naval Facilities Engineering Command
Attn: 09PA, Public Affairs Office
258 Makalapa Dr., Suite 100
JBPHH, Hawaii 96860

Re. Comments on Draft EIS/OEIS for CNMI Joint Military Training Project

Dear Sir or Madam:

This letter provides the comments of the Office of the Governor and the Lieutenant Governor of the Navy's Draft Environmental Impact Statement/Overseas Environmental Impact Statement (the "Draft EIS") for the proposed Commonwealth of the Northern Mariana Islands Joint Military Training Project (the "CJMT" or "Project").

The people and government of the Commonwealth of the Northern Mariana Islands understand their strategic location in the Western Pacific, and have a long tradition of supporting the United States military. Our government has provided two-thirds of the island of Tinian and the entire island Farallon de Medinilla to the United States for military training purposes. Our citizens volunteer to serve in the Armed Forces at rates far exceeding the average in the fifty states. And our entire community has worked hard to develop a close and collaborative partnership with the Department of Defense.

Unfortunately, the CJMT threatens to compromise that partnership. The Navy has proposed to take the entire island of Pagan for large-scale, live fire training (including artillery, aerial, and ship-to-shore bombardment) and to radically and unilaterally alter the previously-agreed activities carried out on the military use portion of the island of Tinian.

As proposed, these actions represent an existential threat to our tourism-driven economy, our fragile ecosystem, our cultural resources, and indeed our way of life.
I must respectfully insist that the Navy withdraw and re-consider its proposal. I am confident that a collaborative good-faith analysis will reveal other, less-damaging alternatives and I stand ready to work with you to that end.

Very respectfully,

ELOY S. INOS

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MEMORANDUM

To: The Honorable Eloy Inos, Governor

From: Nicholas C. Yost
Matthew G. Adams
Jessica L. Duggan

Date: September 30, 2015

Subject: Comments on Draft Environmental Impact Statement for the Commonwealth of the Northern Mariana Islands Joint Military Training Project

This Memorandum provides our comments on the Draft Environmental Impact Statement ("Draft EIS") prepared by the United States Department of the Navy for the proposed Commonwealth of the Northern Mariana Islands Joint Military Training Project ("Project" or "CJMT").

At your request and direction, we have reviewed the Draft EIS; all technical appendices made available to the public in connection with the Draft EIS; other environmental review documents prepared by the Department of Defense in connection with projects in Guam and the Commonwealth of the Northern Mariana Islands ("CNMI"); and additional material relevant to the Project, including information obtained in interviews with CNMI regulatory agencies and their staff.

That review has revealed the Draft EIS to be a woefully inadequate document, which, unless thoroughly revised and re-circulated for a second round of public review and comment, will not support a defensible Navy decision on the CJMT.

Indeed, the Draft EIS fails to meet even the most basic requirements of the National Environmental Policy Act ("NEPA"):

- An EIS must rigorously explore and objectively evaluate ***all*** reasonable alternatives to a proposed project; the Draft EIS is strictly limited to the Navy's preferred training location, and fails to address other reasonable (and less-damaging) alternatives.

- An EIS must include a detailed discussion of all reasonably foreseeable environmental impacts of a proposed project, as well as an assessment of the significance of each one; the Draft EIS fails to address the obvious cumulative impacts of the Navy's decade-long buildup in the Marianas and does not disclose the significance of the CJMT's environmental consequences even in cases where such disclosures are required by law.

- An EIS must identify and discuss measures to mitigate adverse environmental impacts; the Draft EIS fails to discuss mitigation measures for the CJMT's adverse impacts, instead making vague promises to "consider" mitigation at a later time, outside the public eye.

- In preparing an EIS, agencies must meaningfully involve the public and integrate their NEPA compliance with other planning and environmental requirements; here, the Navy has taken steps which exclude speakers of Chamorro and Carolinian (both of which are official languages of the CNMI) from the process, and its Draft EIS provides none of the information required for compliance with other federal and CNMI laws applicable to the CJMT.

We elaborate further in the detailed comments below, which have been prepared by a team of specialists led by the principal draftsman of the Council on Environmental Quality's regulations implementing NEPA (40 C.F.R. parts 1500 to 1508).

1. Alternatives

An EIS must "rigorously explore and objectively evaluate all reasonable alternatives" to a proposed federal action (40 C.F.R. § 1502.14). Such an evaluation is "the heart of an EIS" (*id.*) and the courts have "repeatedly recognized that if [an] agency fails to consider a viable or reasonable alternative, the EIS is inadequate" (*Southeast Alaska Conservation Council v. Federal Highway Administration*, 649 F.3d 1050, 1056 (9th Cir. 2011); *see also 'Ilio'ulaokalani Coalition v. Rumsfeld*, 464 F.3d 1083, 1095 (9th Cir. 2006) ("The existence of a reasonable but unexamined alternative renders an EIS inadequate")).

Under NEPA, an alternatives analysis is not merely a matter of paperwork (40 C.F.R. §§ 1500.1(c), 1500.2(b)) or an exercise in justifying pre-existing agency preferences (40 C.F.R. §§ 1502.2(g), 1502.5). Rather, it is an "action-forcing" requirement whereby agencies must "identify and assess the reasonable alternatives *that will avoid or minimize adverse effects*…upon the quality of the human environment" (40 C.F.R. § 1500.2(e) (emphasis added)). Those alternatives must then be "presented in comparative form" in the EIS, "thus sharply defining the issues and presenting a clear basis for choice by the decisionmaker and the public" (40 C.F.R. § 1502.14).

The Navy has not followed these requirements. Rather than engaging in a good-faith analysis of training options throughout the Pacific, the Draft EIS presents a biased perspective that is transparently intended to justify the Navy's preferred sites in the CNMI. And rather than evaluating a range of training locations, activities, or intensities that could avoid or minimize the Project's quite considerable adverse consequences, the Draft EIS is strictly limited to single option: A full suite of unit-level training activities on Tinian, with a full suite of combined-level training activities on Pagan.

More specifically, the analysis of alternatives in the Draft EIS is legally deficient for each of the following reasons:

- As noted above, NEPA requires the Navy to "rigorously explore and objectively evaluate all reasonable alternatives" (40 C.F.R. § 1502.14). But the Draft EIS fails to evaluate any alternatives outside the CNMI. At least the following reasonable alternatives must be considered:
    - Training in Japan and Korea. U.S. forces can and do use training ranges in both countries.

- Training in Australia. U.S. forces regularly train in Australia, and the two countries recently agreed to a long-term extension of that arrangement (*see* **Exhibits A** and **B**). Training activities carried out in Australia include (but are not limited to) large-scale live-fire amphibious exercises (*see* **Exhibits C** and **D**).

- Training in the Philippines. U.S. forces have trained in the Philippines for many years (*see* 2010 QDR at 28). A recent agreement allows U.S. troop rotations through multiple bases in the Philippines (**Exhibit E**). Training activities carried out in the Philippines include (but are not limited to) large-scale live-fire amphibious exercises in island environments (**Exhibit F**). The Department of Defense has pointed to U.S. training in the Philippines as a model to be followed elsewhere (*see* 2010 QDR at 28).

- Training in Hawaii. The Department of Defense already maintains multiple testing and training ranges in the Hawaiian Islands, an archipelago several times larger than the CNMI. The Draft EIS should have fully evaluated the possibility of using those existing ranges (or moderate expansions thereof) to meet some or all of the Navy's training needs.

- Training in Chuuk or Palau. We understand the Navy has suggested that it could move the activities proposed in the CJMT to Chuuk or to Palau if the CNMI does not approve a land use agreement allowing military training on Pagan. Presumably, the Navy would not have made this suggestion if Chuuk and Palau were not reasonable alternatives.

• The Navy's own documents admit that the CJMT EIS must fully evaluate and pursue alternatives outside the CNMI:

  - Appendix A of the Navy's 2013 *Training Needs Assessment* states "Although the study's primary proposed option is to develop new training ranges and increase capabilities at existing ranges in the [Marianas], it is critical that other options are researched in the EIS as required by the National Environmental Policy Act to ensure a complete and justifiable EIS."

  - Likewise, Appendix C of the *Training Needs Assessment* provides the following direction to Marine Corps Forces, Pacific: "To develop reasonable alternatives which meet the requirement of the National Environmental Policy Act, please…examine the potential of existing ranges both within U.S. territories ***and overseas***" (emphasis added).

- In failing to evaluate alternative locations for training, the Draft EIS bears a striking resemblance to other military analyses which have been struck down by the courts:

  - *'Ilio'ulaokalani Coalition v. Rumsfeld*, 464 F.3d 1083 (9th Cir. 2006) concerned a proposal to convert an infantry brigade to a Stryker unit. Despite the Army's insistence that Hawaii was the only reasonable location for the Stryker unit, the Ninth Circuit held that other locations (including distant bases in Washington and Alaska) had to be evaluated.

  - Likewise, in *Not 1 More Acre v. Department of the Army*, 2009 U.S. Dist. Lexis 81000 (D. Colo. 2009), the court struck down an EIS for a military training project that failed to evaluate alternative locations.

- The Navy has attempted to justify its failure to consider alternatives outside the CNMI by alleging that there is a "training deficiency" in the Marianas. The argument is not supported by the documentary record:

  - Virtually all of the training scenarios identified in the Draft EIS contemplate the involvement of personnel from outside the Marianas (*see* Draft EIS at 2-13 to 2-15 (six of seven unit-level scenarios); 2-19 to 2-20 (all five combined-level scenarios)). In fact, many of the personnel who are proposed to use the CJMT would come from foreign countries (*id*.). If it is feasible to bring personnel from outside the Marianas to train in the CNMI, it is just as feasible for personnel within the Marianas to train elsewhere.

  - The fact that most of the users of the CJMT would come from outside the Marianas (including foreign nations) strongly suggests that the "training deficiency" referenced by the Navy is not so great as to justify the full capacity of the facilities proposed in the Draft EIS. The Navy should have considered whether its needs could be met by using (or expanding) existing training facilities rather than building new ones.

- The Navy also claims that the training facilities proposed in the Draft EIS are the only ones that fit within its "Purpose and Need" (Draft EIS at 2-149). On its face, there is nothing in the Draft EIS's statement of Purpose and Need that requires the Navy's training activities to be limited to those proposed in the CJMT. And even if there were, the Navy would not be excused from broadening its analysis. The courts have made it quite clear that "[a]n agency may not design the objectives of its action in terms so unreasonably narrow that only one alternative…would accomplish the goals of the agency's action" (*National Parks & Conservation Association v. Department of the Interior*, 606 F.3d 1058, 1070 (9th Cir. 2010)). If the current version of the CJMT is truly the only project that fits within the Navy's stated Purpose and Need, the Draft EIS must be revised and recirculated with a broader Purpose and Need statement (*id*.).

- Perhaps seeking to avoid that outcome, the Navy has drafted the Draft EIS <u>*as if*</u> the document contains multiple alternatives (*see* Draft EIS at 2-30 to 2-146). But there are no meaningful differences among the different options identified in the document. That fact is perhaps best illustrated by Tables 4.20-1 and 4.21-2, which purport to compare and summarize the Navy's "alternatives" but do not identify a single environmental distinction between the different options (*see* Draft EIS at 4-547 to 4-554 (Tinian options identical), 4-555 to 4-558 (Pagan options identical)). The absence of any environmental differences among the "alternatives" is not surprising, for there is no evidence that the Navy's consideration of alternatives was in any way linked to its environmental analysis. Although the training activities comprising the CJMT would cause massive environmental damage to both Tinian and Pagan, each of the "alternatives" evaluated in the Draft EIS involves the same activities on the same two small islands (Draft EIS at 2-30 to 2-146). NEPA prohibits such an approach (40 C.F.R. §1502.14 (alternatives analysis must be "based on" consideration of environmental information); *see also W. Watersheds Council v. Abbey*, 719 F.3d 1035, 1050-51 (9th Cir. 2013) (striking down alternatives analysis where there was "no meaningful difference between the four alternatives considered")).

- Some of the documents on which the Navy based its decision-making about the scope of the Draft EIS's alternatives analysis were not made available on the CJMT project website and therefore cannot be reviewed. But it appears that those documents were not interpreted or applied in a consistent fashion. For example, the Navy seems to have applied certain "minimum training area requirements" to eliminate alternatives to training on Tinian from consideration despite the fact that Tinian itself does not meet those same requirements.

- The Navy's alternatives analysis is inconsistent with its own prior analyses. For example, the Record of Decision for the Navy's 1999 Mariana Islands Range Complex ("MIRC") project concluded that Unai Chulu was unsuitable for amphibious assault vehicle training, but each of the three "alternatives" in the Draft EIS now proposes Unai Chulu as *the only* suitable site for such training (*see* Draft EIS at 2-31 to 2-108)).

- Finally, we note that some of the documents on which the Navy has relied inaccurately assume that there is "public support for building and operating ranges linked to residents of the CNMI identify[ing] as American territories and commonwealths proudly supporting U.S. forces" (*see* 2013 *Training Needs Assessment,* page 2-9). It is true that the residents of the CNMI proudly support U.S. forces; in fact, the rate of military service in the CNMI far exceeds the average rate in the 50 states. But it is equally true that the people of the CNMI generally do not support the CJMT in its current form — and the specific jurisdictions in which the Project would be implemented (Tinian and Pagan), are strenuously opposed.[1] For this reason, too, the Navy must expand the scope of its alternatives analysis to include other locations.

[1] The government of Tinian has been especially clear in its position: "[T]he people of Tinian oppose and will continue to oppose any plans to carry out the training described in the CJMT EIS. We will do everything that we can — legally, politically, and socially — to protect our families, our culture, and our island" (**Exhibit G**).

Put simply, the Navy has ignored NEPA's most fundamental commands: *all reasonable alternatives* must be evaluated, and such evaluation must be *based on environmental information and analysis*. Additional, less-damaging alternatives — including, but not limited to, locations outside the CNMI — must be fully evaluated.

2. Environmental Analysis

An EIS must provide a detailed analysis of all reasonably foreseeable direct, indirect, and cumulative environmental impacts of a proposed project, as well as an assessment of the significance of each one (42 U.S.C. § 4332(2)(C); 40 C.F.R. §§ 1502.16, 1508.7, 1508.8, 1508.25(c), 1508.27). Federal agencies are responsible for insuring the "professional integrity" and "scientific integrity" of such analysis (40 C.F.R. § 1502.24). The Navy has not lived up to those responsibilities.

a. Scope of Analysis

The scope of the Draft EIS is improper in multiple respects:

- NEPA requires that connected, cumulative, and similar actions be evaluated in a single EIS (40 C.F.R. § 1508.25(a)). The CJMT is one of four military training projects proposed to be implemented in the CNMI (the others being the Navy's Mariana Islands Training and Testing project ("MITT"), the Navy's Guam and CNMI Military Relocation project ("Relocation"), and the Air Force's Divert Activities and Exercises project ("Divert")). The four actions share a common timing and geography, will impact the same resources, and may (depending on the Navy's perspective) depend for their justification on a common plan (*see* 40 C.F.R. §§ 1502.4, 1508.25(a)). To date, however, they have been evaluated in four separate NEPA documents, *none of which fully evaluates a single alternative outside the CNMI*. As a result, the true environmental consequences of military training in the CNMI have been obscured and CNMI residents have been denied the opportunity to meaningfully address the full scope of the military's proposals. In order to correct this fundamental error, the Navy must take one of two paths:
    - If MITT, Relocation, and CJMT are (i) interdependent parts of a single action or (ii) otherwise connected, the Navy must immediately prepare a Supplemental EIS addressing all three projects (and considering the cumulative impact of those projects together with the Air Force's Divert project) before taking further steps to implement any of them; or
    - On the other hand, if MITT, Relocation, and CJMT are *not* (i) interdependent parts of a single action or (ii) otherwise connected, the Navy must immediately prepare and re-circulate for public review a revised project-specific Draft EIS for the CJMT which fully evaluates reasonable training alternatives outside the CNMI.
- The Draft EIS proposes to give the Navy control over the entire island of Pagan for military training. But the document fails to specify how many years that training (and control) will continue (*see* Draft EIS at 113 to 2-148). Without knowing the temporal scope of the CJMT, there is no way to meaningfully evaluate the Project's long-term

environmental consequences (*see* 40 C.F.R. § 1502.16 (requiring evaluation of long-term consequences)).

- The body of the Draft EIS states that the Navy's live-fire training activities will be limited to 16 (Pagan) or 20 (Tinian) weeks per year (Draft EIS at 2-3). But one of the Navy's technical appendices presents an "unconstrained training concept" involving up to 45 weeks per year of live-fire training (*see* Draft EIS Appendix C). The "unconstrained training concept" strongly suggests that the Navy's true intention is to develop a much larger and more intensive training project. If that is true, the "unconstrained training concept" must be fully evaluated *in this EIS*. Or, if the Navy is willing to guarantee that live-fire training will remain limited to 16 (Pagan) or 20 (Tinian) weeks per year, the "unconstrained training concept" should be completely removed from the Draft EIS and the administrative record should be clarified to reflect the Navy's commitment.

- The Draft EIS admits that implementation of the CJMT will involve both (i) a new dock and breakwater on Pagan and (ii) relocation of the existing International Broadcast Bureau ("IBB") facility on Tinian. But the document provides only a vague "programmatic" analysis of those portions of the Project (*see* Draft EIS at 2-3 ("anticipated to be needed and would be implemented"), 4-503 to 4-536 (programmatic analysis)). There is no legal or environmental basis for the Navy's decision to conduct a lesser "programmatic" review for these individual Project components — the need for them is clear and the Navy has access to all of the information necessary for a thorough review (*see* 40 C.F.R. § 1502.22). By withholding a complete environmental analysis of the IBB relocation and the Pagan dock and breakwater, the Navy has impermissibly segmented its environmental review and prevented effective public comment on the full impacts of the CJMT.

b. Improper Assumptions

The Navy's environmental analysis is based on a series of improper assumptions which contaminate the entire Draft EIS:

- The Draft EIS evaluates "construction impacts" and "operational impacts" separately, despite the fact that construction activities will overlap with operations. As a result, the document significantly underestimates the overall environmental impacts of the Project during periods of overlap.

- The Draft EIS assumes, without detailed analysis, that most construction activities will be insignificant because they are temporary. It is true that some of the Project's impacts will last longer than others. But insignificance cannot be *assumed* — even temporary activities can have significant consequences.

- The Draft EIS assumes Pagan is currently uninhabited and will remain so for the foreseeable future. Both assumptions are inaccurate. Pagan has a permanent population. In addition, the island is regularly used for eco-tourism, fishing, traditional gathering, and recreation, among other purposes. Moreover, CNMI law lays out a process by which Pagan residents who were displaced by the 1981 eruption of Mount Pagan can re-settle the island. By failing to account for these facts, the Navy has (i) neglected to address many of the Project's impacts on Pagan and its residents and (ii) significantly under-estimated the extent of those impacts which have been addressed. There is no reasonable justification for this error — accurate information about Pagan is readily available from a variety of sources, including the Northern Islands Mayor's Office.

c. Environmental Baseline

The Navy has made two fundamental errors with respect to the environmental baseline for the Project (*i.e.,* the conditions to which the Project's impacts must be compared), both of which require thorough revision and recirculation of the Draft EIS:

- Although recognizing that "[p]otential impacts cannot be determined without first understanding the existing conditions in the affected environment" (Draft EIS at 3-1), the Draft EIS does not, in fact, use existing conditions as an environmental baseline. Instead, it inaccurately assumes that the Relocation project will be fully implemented before the CJMT begins. In doing so, the Navy has severely under-estimated the cumulative impacts of the CJMT and the Relocation (*see also* part 2(p), below).

- Several of the analyses presented in the Draft EIS lack meaningful baseline data; instead, the Navy promises to conduct the necessary information as part of its post-approval mitigation measures (*see, e.g.,* Draft EIS at 4-39 (describing groundwater conceptual site model)). The courts have consistently held that such an approach violates NEPA (*see, e.g., Northern Plains Resource Council v. Surface Transportation Board*, 668 F.3d 1067, 1083-85 (9th Cir. 2011)).

d. Land Use and Submerged Lands

- The Navy's preferred alternative involves acquisition of the entire island of Pagan and an additional 470 acres on Tinian. The Draft EIS dismisses this impact as "less than significant" on the ground that the acquisitions represent a small percentage of the land already leased by the military. That is not an appropriate threshold of significance; the proper inquiry is whether the proposed acquisitions will significantly impact the CNMI's remaining land, taking into account both the legal and cultural context of the proposed acquisition.

- The Draft EIS fails to address the Project's potential to interfere with homestead rights and processes on both Pagan and Tinian.

- The Project is fundamentally incompatible with applicable land use requirements:

    - The lease agreement governing military use of Tinian requires that the Navy restore and remediate damage to the island at the close of the lease period. The Draft EIS admits that the CJMT will result in permanent environmental impacts that cannot be remedied, raising very significant questions about whether the CJMT is consistent with the lease.

- The Draft EIS seems to assume that the Navy has an existing right to the groundwater underlying the island of Tinian. Neither the *Covenant to Establish a Commonwealth of the Northern Mariana Islands in Political Union with the United States* nor the *Technical Agreement Regarding Use of Land to be Leased by the United States in the Northern Mariana Islands* nor any of the lease agreements between the United States and the CNMI appears to provide such a water right.

- In executing the *Covenant* governing its relations with the CNMI, the United States pledged to "continue to recognize and respect the scarcity and special importance of land in the Northern Mariana Islands." Among other things, the *Covenant* provides that the United States will minimize its acquisition of land within the Commonwealth and will refrain from any involuntary acquisition unless absolutely necessary. The *Covenant* also states that the United States does not anticipate any need for military use of Pagan. The portion of the CJMT proposed for Pagan appears to violate each of these principles: It would involve a substantial acquisition of land against the will of the people; it would result in the militarization of Pagan; and it would authorize the acquisition of an interest in the entire island even though only a portion would be used.

- The Draft EIS fails to address the indirect land use impacts of proposed training activities on Tinian:

  - The Project's impacts on rare, endangered, threatened, and candidate species will create a need for additional conservation areas, wildlife preserves, and compensatory mitigation projects, all of which will further restrict civilian land use outside the Navy's Military Lease Area. This issue is particularly significant in light of the United States Fish & Wildlife Service's recent decision to list 23 new endangered species in Guam and the CNMI.

  - The Draft EIS states that trainees are expected to have time off for recreation and entertainment in Tinian. The island currently lacks facilities capable of accommodating the number of trainees anticipated; additional development is almost certain to be needed. The Draft EIS does not address these growth-inducing impacts.

- The Surface Danger Zones proposed in the Draft EIS would effectively regulate use of land and submerged lands on Saipan over which the CNMI has jurisdiction. The Draft EIS fails to address this fundamental jurisdictional conflict.

- The Draft EIS refuses to address the Project's inconsistency with applicable CNMI land use and environmental laws, suggesting that the issue can be avoided until a future Coastal Zone Management Act ("CZMA") review. The Navy's position is incorrect as a matter of law:

  - Inconsistencies with CNMI law must be disclosed, evaluated, and mitigated *as part of this EIS* (40 C.F.R. §§ 1502.16(a)-(c), 1508.27(b)(10)).

- o As explained in greater detail below, NEPA requires that preparation of an EIS be *integrated with* "other planning and environmental review procedures required by law," including CZMA review (40 C.F.R. § 1500.2(c); *see also* 40 C.F.R. §§ 1500.4(k), 1502.25, 1506.2).

e. Cultural Resources

- The Navy has not done an adequate job of identifying or evaluating the historic and cultural resources that may be affected by the Project:
  - o The Navy has proposed to acquire a "real estate interest" in the entire island of Pagan. But the Navy has completed historic and cultural resource surveys for fewer than 600 acres (out of a total of approximately 11,680 acres) on the island. The Navy's failure to complete all needed cultural and historic resource surveys is especially problematic because the training proposed for Pagan would not be restricted to established roads, paths, or zones (*see* Draft EIS at 2-121).
  - o The Navy's consultants have prepared a set of studies purporting to address Traditional Cultural Properties ("TCPs"). To our knowledge, the studies have not been provided to the public — not even in redacted form. The TCP studies accurately acknowledge the existence of three TCPs on Tinian (Unai Chulu, Unai Dankulo, Puntan Masalok) and six others on Pagan (Regusa Beach, Apansanmena Beach, Paliat, Pialama, Shomshon Beach, and the area surrounding a certain medicine stone), most of which are related to the locations of traditional fishing activities. But the studies fail to properly recognize other TCPs, including those associated with traditional gathering, agriculture, and *latte* sites. In its Relocation EIS, the Navy acknowledged the significant cultural importance traditional gathering activities and *latte* sites on Guam. The Draft EIS for the CJMT provides no justification for the Navy's failure to accord those resources the same respect in the CNMI.
  - o The House of Taga is one of the most important historic and cultural resources in the CNMI. The CJMT would route heavy truck traffic along narrow roads nearby and adjacent to the House of Taga. The Draft EIS fails to evaluate whether such traffic — and the noise, vibration, and pollution it would bring — will significantly impact the House of Taga or its context.
- Although only a small portion of Pagan has been surveyed, the results of those surveys clearly establish the island's deep cultural and historic significance: More than 180 archaeological and historic sites, of which at least 110 are deemed eligible for listing in the National Register of Historic Places. The numbers on Tinian are even greater: The CJMT would have significant, direct impacts on nearly 200 National Register-eligible sites. These are not suitable locations for destructive live-fire training. Reasonable alternatives must be fully evaluated.

- The Draft EIS misleadingly suggests that the Navy will avoid potential impacts to cultural resources by limiting its use of amphibious assault vehicles to certain beaches. Three beaches on Tinian have been identified as TCPs eligible for listing in the National Register, and all three are among the "certain beaches" selected by the Navy for amphibious training. In fact, the only in-water construction associated with the Navy's use of amphibious assault vehicles will destroy one of the character-defining features of the Unai Chulu TCP.

- The CJMT proposes repeated use of heavy, tracked vehicles within North Field National Historic Landmark, risking damage to the Landmark's historic landscape and runways. The Draft EIS claims that the impact will be avoided through the construction of "gravel roads adjacent to the historic roads." But construction of a new system of gravel roads would alter the National Historic Landmark's cultural landscape, a significant impact in its own right.

- Despite (i) the unquestionable significance of the Project's impacts on historic and cultural resources and (ii) the Navy's failure to properly identify all potentially-affected resources, the Draft EIS fails to provide any meaningful discussion with respect to treatment, study, or avoidance of historic and cultural resources discovered during training.

- The Navy has impermissibly deferred development of specific cultural resource mitigation and avoidance measures pending the outcome of a review process conducted under Section 106 of the National Historic Preservation Act. The Navy's approach is contrary to law (*see* parts 3 and 5, below) and deprives the public of an opportunity for meaningful input.

- The Draft EIS' approach to mitigation is particularly problematic because there are substantial questions about whether the CJMT is consistent with the training limits agreed to by the Navy as cultural resource mitigation measures for the 2009 MIRC and the 2010 Relocation projects. The document must be revised to (i) specifically identify those limits and (ii) evaluate whether CJMT will be consistent with them

f. Socioeconomic Impacts (Including Recreation, Tourism, and Public Services)

- Tourism is the primary economic engine of the CNMI, and the vast majority of the tourists who visit the Commonwealth are drawn by its natural and cultural resources. Thus, the economic and social impacts of the CJMT are "interrelated with" the quality of the environment, and must be evaluated in detail (*see* 40 C.F.R. § 1508.14). Such an evaluation can only lead to one conclusion: Large-scale, live-fire military training is fundamentally incompatible with tourism in the CNMI. No one chooses to vacation in a war zone. By directly (*e.g.,* limiting access to recreational opportunities) and indirectly (*e.g.,* diminishing the appeal of beaches and viewsheds) undermining tourism, the CJMT will have a very substantial impact on the economy of the CNMI and the self-sufficiency of its residents.

- The Draft EIS does not provide any meaningful analysis of one of the most critical socioeconomic questions raised by the CJMT: The extent to which the Navy considers the Project to be consistent with the CNMI's existing visa parole program for Chinese and Russian visitors. One of the background sections of the Draft EIS accurately explains that (i) the CNMI's economy is largely dependent on tourism; (ii) the tourism sector relies on Chinese and Russian visitors; and (iii) the CNMI's ability to attract substantial numbers of Chinese and Russian visitors is attributable to the visa parole program (*see* Draft EIS at 3-244 to 3-251). But the portion of the Draft EIS addressing "Environmental Consequences" fails to explain whether increased military presence in the CNMI might require (or otherwise lead to) restrictions on Chinese or Russian visitation (*see* Draft EIS at 4-433 to 4-456). This is an issue of the highest importance, and it must be dealt with in a transparent and straightforward fashion in the EIS. There are two options:

    - If the Navy is willing to confirm that the CJMT will not affect the CNMI's existing visa waiver parole program, whether now or in the future, that commitment must be memorialized in (i) an enforceable socioeconomic mitigation measure in the EIS and (ii) as an explicit condition of approval in any Record of Decision that may result; or

    - On the other hand, if the Navy is not willing to make such a commitment the consequences of terminating the visa waiver parole program — consequences which the Mariana Visitor Authority values at more than $500 million per year — must be fully evaluated *<u>in this EIS</u>* as a potential indirect impact of the CJMT.

- The Draft EIS claims that the massive live-fire training activities proposed for Pagan will not interfere with ecotourism (*see* Appendix Q, page 5-5) and, for that reason, the CJMT "is not anticipated to have an effect" (Draft EIS at 4-454). This "analysis" is simply not credible. By definition, ecotourism is wholly incompatible with large-scale live-fire military training.

g. Airspace and Transportation

The socioeconomic impacts noted above are intertwined with and heightened by the CJMT's significant effects on airspace and transportation to, from, and within the CNMI:

- The CJMT would very substantially increase the amount of traffic at the Port of Tinian. The Draft EIS fails to provide information necessary to determine whether that increase can be accommodated without significant dredging, repairs, and other infrastructure upgrades. Any reasonably foreseeable changes to the Port of Tinian must be evaluated *<u>in this EIS</u>* so that the full environmental consequences of the Project (and alternatives thereto) can be properly considered.

- The CJMT would add 8,768 military air operations per year at Tinian International Airport (a 1,842% increase in military operations) while simultaneously imposing significant new airspace restrictions on civilian flights. For all practical purposes, it would transform the airport into a military base.[2] Such a result would be inconsistent with the terms of the 1999 lease agreement between the United States and the CNMI, which recognizes that Tinian International Airport should remain a civilian facility. It would also forfeit a substantial amount of federal and CNMI investment into building the airport's civilian air capacity — more than $22 million since 2000 (*see* **Exhibit H**). The Draft EIS fails to address either of these issues.

- The CJMT would also limit arrival routes into Saipan International Airport, the CNMI's sole commercial link to the rest of the United States. The Draft EIS promises that this issue will be addressed in a post-approval "aeronautical study." That is not sufficient. Because the Draft EIS (i) does not identify specific routes that will guarantee appropriate commercial air access to Saipan International Airport and (ii) does not address the potential consequences to the CNMI of losing such access, it fails to provide a "hard look" at the proposed project's direct impacts (*e.g.,* changes to air service) and indirect impacts (*e.g.,* changes in noise patterns, socioeconomic impacts) on airspace and transportation (*see Northern Plains Resource Council*, 668 F.3d at 1083-85).

- More fundamentally, the Draft EIS fails to appreciate the importance of regular, efficient, and inexpensive civilian air service in the CNMI. Residents of Saipan and Tinian count on that service as a way to commute to work, a way to maintain and grow the CNMI's tourist economy, and a way for residents of Tinian to access emergency medical care not provided on their home island. Any change that would make civilian air service between Saipan and Tinian less reliable, less frequent, longer, or more expensive would be devastating to the residents of both islands. The Draft EIS must be revised to address these issues, keeping in mind (i) the fact that the commercial fleet operating between Tinian and Saipan consists primarily of single-engine aircraft and (ii) the FAA's restrictions on over-water operation of such aircraft.

- The Draft EIS proposes a "see-and-avoid" procedure "to ensure the safe separation" of military and civilian aircraft "as they do today" (Draft EIS at 4-138). The Navy appears to be assuming that current airspace procedures will be sufficient to guarantee civilian safety even during the implementation of the CJMT. That assumption is flawed in multiple respects:

  - Civilian air traffic is not safe from military aircraft, even under current conditions and procedures. For example, in March, 2015 a pair of military transport aircraft violated existing communications protocols and nearly collided with a civilian commuter flight (*see* **Exhibit I**).

  - Even if current procedures were perfectly safe for civilian aircraft, they would not suffice for purposes of the CJMT. As noted above, the CJMT would increase military air operations at Tinian International Airport by 1,842%.

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[2] In this respect, the CJMT differs from the Tinian options associated with the Air Force's proposed Divert project.

h. Environmental Justice

- Executive Order 12898 requires the Draft EIS to identify and address "disproportionately high and adverse human health or environmental effects" on "minority populations" in "the United States and its territories and possessions." The Council on Environmental Quality ("CEQ"), the federal entity charged with overseeing the implementation of NEPA throughout the federal government, has directed that for purposes of the Executive Order, "minority populations" include "Pacific Islanders" such as the residents of the CNMI (*see* CEQ, "Environmental Justice Guidance Under the National Environmental Policy Act" (1997)). Here, the Navy has proposed one of the most impactful projects imaginable — live-fire ground, aerial, and naval bombardment — for a pair of small islands containing significant minority populations ***<u>without considering any other locations</u>***. Even worse, the specific sites chosen by the Navy contain cultural resources of particular importance to those very same minority groups. On its face, this is a significant environmental justice impact that demands a good-faith effort to identify alternatives.

- Rather than squarely confronting the environmental justice implications of the Navy's proposal, the Draft EIS attempts to bury the issue:

    - The Draft EIS concludes that training on Tinian will not create an environmental justice problem because the Project will impact all Tinian residents equally. In doing so, it ignores both the letter and the spirit of environmental justice. The harms and risks of the Navy's proposal to train on Tinian will be borne by the population of Tinian. That population consists almost exclusively of low-income, minority, and indigenous individuals. The Navy has not considered a single training alternative that would avoid impacting those individuals. This is the epitome of an environmental justice problem.

    - The Draft EIS assumes the environmental justice implications of training on Pagan can be ignored because the island is uninhabited. As explained above, that assumption is unfounded. And even if Pagan were truly uninhabited, the CJMT's disproportionate impacts on the island's cultural and environmental resources — both of which are particularly valued by displaced Northern Islanders, a minority population within a minority population — would require a finding of significance.

i. Noise

- The Draft EIS admits that the CJMT would produce "noise events [that] could be intrusive for speech interference, classroom interruptions, and sleep disturbance" (Draft EIS at 4-106), but does not propose any alternatives or mitigation that would avoid those impacts.

- The Draft EIS does not fully identify the climate, land use, and topography assumptions used in the Navy's noise modeling. As a result, it is not possible to determine whether the results of that modeling are valid.

- The Navy admits that "peak sound levels" will exceed quantitative significance thresholds. The Draft EIS misleadingly attempts to downplay this impact as the product of "unfavorable weather" conditions (*see* Draft EIS at 4-90 to 4-101). In fact, it is the product of the CJMT itself.

- The Draft EIS appears to evaluate noise from each of the different training activities proposed by the Navy (small caliber, large caliber, artillery, aerial, etc.) separately. The document does not seem to account for the fact that multiple training activities are likely to occur simultaneously.

- The Draft EIS focuses on absolute noise levels. But noise increases (regardless of absolute levels) can also result in significant, adverse environmental effects. Federal agencies generally consider a 5-decibel increase to be significant. The Navy admits that residents of Tinian will experience noise increases of up to 19 decibels. The Draft EIS does not squarely address or mitigate this issue.

- The Navy's overall conclusion — less than significant noise impacts — ignores local conditions and experiences:

    - Tropical climate and high electricity costs combine to force significant numbers of CNMI residents to keep their windows and doors open at all times. As a result, they are especially sensitive to noise impacts. There is no evidence that the Draft EIS accounts for these facts.

    - Previous training on Tinian has subjected residents to noise levels so severe that classes had to be cancelled and students were sent home from school. This information was readily available from local officials. It should have been included and addressed in the Draft EIS.

    - Sonic booms associated with previous training have resulted in broken windows and other property damage on Tinian and Saipan. Again, this information was readily available and should have been included in the Draft EIS.

- The Draft EIS fails to confront the long record of substantial noise damage associated with military training activities. For example, a Japanese court recently awarded more than ¥750 million in noise-related damages to 2,200 residents of a village near Futenma air base in Okinawa. The Navy must openly and honestly confront the fact that the CJMT would import this type of damage to Tinian, an American municipality. Again, less-harmful alternatives must be evaluated.

j. Visual Resources

- The Draft EIS improperly limits its evaluation of visual resources to a few "key observation points" on Tinian (Draft EIS at 4-364 to 4-384). Other areas are not evaluated. As a result, the Draft EIS fails to address the overall visual environment.

- The Draft EIS also fails to confront the fact that many Surface Radar Sites and Observation Towers proposed for Tinian would be visible from sensitive locations, including Unai Chulu, Unai Babui, and Ushi Point (Draft EIS at 4-366 to 4-379).

- The Navy has adopted an impermissibly restrictive approach to viewsheds within the North Field National Historic Landmark. "Key Observation Point 1" is not the only important place in this extremely sensitive visual environment (*see* **Exhibit J**; *see also* Department of the Navy, "Tinian North Field Cultural Landscape Report").

- The Draft EIS fails properly to address indirect impacts on visual quality associated with increased risks (Draft EIS at 4-364 to 4-384). A single wildfire ignited by live-fire training could easily change the visual character of Tinian or Pagan for decades.

k. Geology and Soils

Impacts to geology and soils are extremely important in island environments, where even small amounts of erosion can have very significant ecosystem impacts. The Draft EIS does not fully address these issues:

- The Draft EIS estimates that the Navy's preferred alternative would result in direct ground disturbance equal to approximately 9% of the usable land on Tinian and 10% of the usable land on Pagan.[3] Disturbing this much land at once is simply not acceptable in a sensitive island environment, particularly where (as here) no meaningful alternatives have been considered and no specific mitigation has been proposed.

- The Draft EIS states that the Navy's preferred alternative would result in approximately 785 acres of new impervious surface on Tinian (Draft EIS at 4-17). For context, this would be nearly the equivalent of paving every square inch of land in Central Park — again, far too much for a small island like Tinian (which is the approximate size and shape of Manhattan).

- Actual disturbed and impervious surfaces are likely to be even greater than estimated in the Draft EIS. The document admits that repeated use can render soils impervious, but it does not appear to include all areas of repeated use (firing positions, observation posts, areas for foot maneuvers, etc.) in its calculation of impervious surface.

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[3] The Navy's 2013 *Siting Study* states there are approximately 23,600 acres on Tinian with a slope less than 30% and approximately 6,848 acres of land on Pagan with a slope less than 30%.

- The significant amount of soil disturbance caused by the Project raises substantial concerns about erosion. The Draft EIS says new stormwater infrastructure will be the primary means of managing this issue on Tinian, but the document does not specify what infrastructure will be built or where it will be located.

- The Draft EIS dismisses the significance of impacts to the beach at Unai Chulu on the basis that the beach is already "vulnerable." This turns proper impact analysis on its head — impacts to Unai Chulu will be significant *precisely because* it is a fragile beach (as the Navy itself has previously acknowledged in connection with the 1999 MIRC project).

- The Draft EIS admits that the Project could create craters up to 6 feet deep on Tinian (Draft EIS at 4-14), but claims this will be a less-than-significant impact because the island's limestone extends below that depth. This is not a credible threshold of significance. Tinian's fragile karst geology can (and will) be significantly impacted even if artillery shells do not pierce the entirety of Tinian's limestone layer.

- Neither the Draft EIS nor any of the Navy's associated technical reports provide any soil data for Pagan.

- The Draft EIS does not address the relationship between erosion and near-shore marine habitats. There is substantial evidence linking live-fire military training with runoff that damages corals and other marine resources (*see* **Exhibit K**).

I. Water Resources

Water quality is closely connected to the geology and soils issues noted above. In addition to the errors associated with the Navy's geology and soils analysis, the Draft EIS fails properly to address water quality in each of the following ways:

- The Navy bases its water quality analysis on the assumption that recommendations from a "Low Impact Development and Drainage Study" will be incorporated into the Project. But no specific information about the Study or its recommendations is provided in the Draft EIS.

- The Project risks damaging Tinian's freshwater lens aquifer via (i) direct contamination and (ii) salt water intrusion. The Navy promises to study these threats in a "pre-versus-post development hydrologic analysis" (Draft EIS at 4-38) to be prepared at some point in the future. That is not sufficient. The analysis must be prepared now and circulated for review as part of a revised Draft EIS (40 C.F.R. §§ 1502.2(g), 1502.9(a)).

- The Navy's analysis of groundwater is based on the assumption that Tinian's aquifer is sub-divided into multiple hydrologically-distinct sub-basins. The Draft EIS does not provide a meaningful scientific basis for that conclusion. We understand the Navy has also refused to provide the CNMI Bureau of Environmental and Coastal Quality ("BECQ") with information on this topic.

- The Draft EIS does not provide the baseline data necessary to evaluate potential impacts on water quality. We understand that BECQ offered to work collaboratively with the Navy to develop such data, but never received a response.

- The Project does not meet applicable CNMI water quality standards or CNMI anti-degradation regulations. The Draft EIS fails to confront this issue.

- The Draft EIS speculates that water quality impacts associated with air cushion landing craft operations are "likely not qualitatively different from naturally occurring turbidity during periods of storm-generated waves" (DEIS at 4-50 to 4-51). The Navy has not provided empirical support for that position.

m. Air Quality and Climate Change

- The Draft EIS admits that the CJMT will exceed relevant air quality thresholds for multiple Clean Air Act criteria pollutants. Indeed, we understand the CJMT will be the largest source of air pollution in the history of the CNMI. The Navy nonetheless asserts that air quality impacts will be less than significant because some emissions would be "regional" or "aerial." The Draft EIS provides no legal, regulatory, or empirical support for its finding of insignificance.

- The Draft EIS appears to evaluate the impacts of activities on Tinian separately from the impacts of activities on Pagan, without considering whether or how the two may combine to contribute to regional air quality issues.

- The Draft EIS fails to explain the assumptions and inputs used for the Navy's air quality modeling, thereby precluding meaningful comments on the modeled results.

- The Draft EIS does not address Toxic Air Contaminants, an important and common problem at port and airport facilities.

- Throughout the Draft EIS, the Navy fails meaningfully to address the problem of climate change in an island environment. The failure is two-fold: (i) the Navy does not seem to recognize the fact that island ecosystems are especially vulnerable to climate change, and, as a result, (ii) the Draft EIS has vastly underestimated long-term impacts (direct, indirect, and cumulative) of the Project. CEQ has determined that these issues are "squarely within NEPA's focus" (79 Fed. Reg. 77802, 77823, 77828-29 (Dec. 24, 2014)).

n. Biological Resources

- The Draft EIS fails to provide an analysis of biological resources that meets accepted standards of professional and scientific integrity (*see* 40 C.F.R. § 1502.24). The Navy relies on stale and incomplete surveys, many of which are outdated and/or inapplicable by their own terms. Moreover, the Draft EIS fails to provide species-specific impact analyses, thereby precluding detailed, meaningful input from the public. Such an approach is contrary to both science and law.

- The Navy has done a woefully inadequate job of addressing invasive species:

    - Several sections of the Draft EIS acknowledge (i) the very significant threat posed by the Brown Tree Snake and (ii) the Navy's culpability in the spread of that species. But the document does not set forth specific mitigation actions capable of addressing this threat; instead, it refers to the ongoing preparation of a regional plan, the contents of which are not provided. The public has had no meaningful opportunity to comment on this issue.

    - The Draft EIS fails to specifically address invasive species other than the Brown Tree Snake.

    - The Navy does not address the question of funding for control of invasive species mitigation. This is a very substantial problem. The CNMI lacks the resources necessary to address the problem on its own.

    - The Draft EIS also fails to address the financial implications of invasive species for tourism, utilities, and other infrastructure, which, by the Defense Department's own admission, can reach hundreds of millions of dollars per year (*see* **Exhibit L**).

- The Navy's proposal to destroy an existing conservation area set aside for the Tinian Monarch — a rare and endemic species — is extremely problematic. The Draft EIS provides no assurance that sufficient replacement habitat can be procured (or even exists).

- The Project involves a large number of amphibious landings, both for training and logistics purposes. Each landing creates a risk of significant damage to aquatic species and their habitats. But the Draft EIS fails to provide complete, accurate and consistent information about the number and location of the amphibious landings contemplated, thereby precluding meaningful review. For example:

    - Table 2.5-1 purports to provide information about total amphibious landings on Pagan. But the Table does not match the accompanying text, and neither the Table nor the text seem to account for the Navy's plans to transport trainees to and from the island via amphibious landing craft.

    - Section 2.4.1.3.6 of the Draft EIS, which purports to address amphibious training operations on Tinian, fails to include specific information about the timing of amphibious training activities (or how that timing might align with, for example, relevant nesting seasons) or the frequency with which each of the island's beaches would be used.

o. Hazardous Materials and Waste

- The Draft EIS fails to provide detailed, quantitative estimates of the amount of hazardous material anticipated to be used on Tinian and Pagan as a result of the CJMT. We understand the Navy has provided such estimates in connection with other projects involving large training ranges.

- The Draft EIS does not provide a reasonable explanation of whether or how waste (human, solid, hazardous, spent munitions, etc.) will be removed from Pagan.

- The preparers of the Draft EIS have failed to confront the Defense Department's long history of non-compliance with its remediation obligations. Of particular relevance is the Navy's ongoing failure to clean up known contamination at Tinian's Chiget Mortar Range, which has been closed since the 1980s. In light of this track record, the Draft EIS must be significantly revised to include ***specific*** procedural, financial, and environmental safeguards capable of assuring prompt cleanup of any contamination on Tinian and Pagan.

p. Cumulative Impacts

- The cumulative impact analysis presented in the Draft EIS relies on the Navy's evaluation of direct and indirect impacts. As a result, it is contaminated with all of the flaws and inaccuracies of that evaluation (described above, as well as in comment letters from CNMI Departments, Bureaus, and residents).

- An EIS must evaluate "the impact on the environment which results from the present impact of the action when added to other past, present and reasonably foreseeable future actions" (40 C.F.R. § 1508.7). But the Draft EIS restricts its analysis of cumulative impacts to actions that that are currently proposed or reasonably foreseeable in the future. In doing so, it fails to address the very substantial cumulative consequences of the CJMT together with other military training projects recently approved for the CNMI, including the Relocation, MITT, and MIRC projects.

- Similarly, the Draft EIS fails to account for cumulative impacts related to projects that may be implemented over the course of many years. Cumulative impacts "can result from…actions taking place over a period of time" (40 C.F.R. § 1508.7). Military actions like the Relocation, MITT, and MIRC projects have already been approved, but have not been fully implemented or completed. They will involve continued military construction and training activities in the CNMI "over a period of time" into the future. These cumulative conditions are not captured in the environmental baseline for the CJMT and were never evaluated in the context of the MIRC, the Relocation, or any other project. If they are not fully addressed ***in this EIS***, they will forever escape review.

3. Mitigation

An EIS must identify and discuss "appropriate mitigation measures not already included in the proposed action or alternatives" (40 C.F.R. § 1502.14(f); *see also* 40 C.F.R. § 1502.16(h)). The Draft EIS falls well short of that requirement. Many of the most significant shortcomings are outlined in part 2, above. In addition:

- For many of the significant impacts identified in the Draft EIS, the Navy has not identified any mitigation at all, a clear violation of NEPA (40 C.F.R. §§ 1502.14(f), 1502.16(h)). Examples include land use impacts on Pagan, recreational impacts on Tinian, marine biology, and visual resources.

- For other significant impacts, the Navy relies on lists of "best management" or "resource management" practices as a substitute for meaningful mitigation measures. The courts have made it quite clear that a "mere listing" of management practices is not sufficient for NEPA compliance (*see, e.g., Neighbors of Cuddy Mountain v. U.S. Forest Serv*., 137 F.3d 1372, 1380 (9th Cir. 1998)).

- For still other significant impacts, the Draft EIS contains nothing but broad statements about potential (but undefined) mitigation possibilities. "[B]road generalizations and vague references to mitigation measures …do not constitute the detail as to mitigation measures that would be undertaken…that [an EIS] is required to provide" (*Neighbors of Cuddy Mountain*, 137 F.3d at 1381 (9th Cir. 1998)).

- Throughout, the Draft EIS fails to provide any reasonable evaluation of the effectiveness of the Navy's proposed mitigation measures. "A mitigation discussion without at least some evaluation of effectiveness is useless..." (*S. Fork Band Council of W. Shoshone v. United States DOI*, 588 F.3d 718, 727 (9th Cir. 2009)). Indeed, CEQ has explicitly directed that "mitigation commitments should be carefully specified in terms of measurable performance standards or expected results, so as to establish clear performance expectations" (*see* 76 Fed. Reg. 3843 (Jan. 21, 2011)). The Draft EIS fails to do so.

4. Public Involvement

Under NEPA, federal agencies "shall to the fullest extent possible…[e]ncourage and facilitate public involvement in decisions which affect the quality of the human environment" (40 C.F.R. § 1500.2(d); *see also* 40 C.F.R. §§ 1500.4(d), 1502.8, 1502.19, 1503.1, 1506.6). That has not happened here. To date, the Navy has not provided any portion of the Draft EIS in Chamorro or Carolinian, two of the three official languages of the CNMI. As a result, significant numbers of CNMI residents have been effectively precluded from meaningful participation in the NEPA process.

We note that there does not appear to be any reason why the Navy could not have provided versions of the Draft EIS in a language other than English — after all, it prepared Chamorro-language material for the Relocation EIS.

5. Other Legal Requirements

Preparation of an EIS must be integrated with "other planning and environmental review procedures required by law or by agency practice so that all such procedures run concurrently rather than consecutively" (40 C.F.R. § 1500.2(c); *see also* 40 C.F.R. §§ 1500.4(k), 1502.25, 1506.2).

Such coordination shall "to the fullest extent possible" include concurrent surveys, studies, and public review required by the National Historic Preservation Act ("NHPA"), Section 4(f) of the Department of Transportation Act ("Section 4(f)"), the Endangered Species Act ("ESA"), the Marine Mammal Protection Act ("MMPA"), and other federal, state, and local environmental review and planning laws (*see* 40 C.F.R. §§ 1500.2(c), 1500.4(k), 1502.25(a), 1506.2; 23 C.F.R. part 774; 36 C.F.R. § 800.8)**.**

a. National Historic Preservation Act

The Navy has failed properly to coordinate the review procedures mandated by the NHPA with the preparation of the Draft EIS.

i. NHPA Section 106

Section 106 of the NHPA requires federal agencies to engage in meaningful consultations to resolve adverse effects on historic resources (*see* 54 U.S.C. §§ 306101-306114; 36 C.F.R. part 800). The NHPA's implementing regulations clearly specify that "the views of the public are essential" to this process (36 C.F.R. §800.2(d)(1)) and that agencies must "provide the public with information about…effects and seek public comment" (36 C.F.R. §800.2(d)(2); *see also* CEQ and ACHP, "Handbook for Integrating NEPA and Section 106" (2013) at 13).

Here, the Navy has not coordinated the Section 106 process with the Draft EIS. The information generated in one process has not informed the results of the other, thereby limiting opportunities for meaningful agency consultation and public participation — precisely the outcome prohibited under both NEPA and the NHPA (42 U.S.C. § 4332(2)(A),(C); 54 U.S.C. §§ 306101-306114; 36 C.F.R. §§800.2(d), 800.8; 40 C.F.R. §§ 1500.2(c), 1500.4(k); 1502.25(a); *see also* 76 Fed. Reg. 3843, 3845 (Jan. 21, 2011)).

ii. NHPA Section 110

Section 110 of the NHPA requires that "[p]rior to the approval of any Federal undertaking that may directly and adversely affect any National Historic Landmark, the head of the responsible Federal agency shall, to the maximum extent possible, undertake such planning and actions as may be necessary to minimize harm to the landmark" (54 U.S.C. §306107).

The Draft EIS ignores this requirement (*see* Draft EIS at 1-22 to 1-23). Information presented in the document (*see* Draft EIS at 4-329 to 4-352) clearly indicates that the CJMT will directly and adversely affect North Field National Historic Landmark — including the character-defining features identified in North Field's National Register Inventory Form (*see* **Exhibit J**) and in the Navy's "Tinian North Field Cultural Landscape Report." But the Draft EIS does not (i) identify or evaluate any training alternatives that would avoid harm to North Field or (ii) explain how the Navy will avoid adverse effects "to the maximum extent possible," as required (*see* Draft EIS at 2-30 to 2-112, 4-329 to 4-352).

b. Section 4(f)

Section 4(f) prohibits transportation agencies from funding or approving projects that would "use" specified types of property (including, as relevant here, historic sites, public parks, and wildlife preserves) unless (i) there is no prudent and feasible alternative and (ii) all possible planning to minimize harm has been completed (49 U.S.C. § 303(c)). This prohibition is not limited to direct, physical uses; it also extends to "constructive uses" — activities that substantially impair the protected attributes of the property in question (23 C.F.R. § 774.15(a)).

Potential uses of Section 4(f) properties "shall be evaluated as early as practicable in the development of the action when alternatives to the proposed action are under study" (23 C.F.R. § 774.9(a)). Where an EIS is being prepared, an agency's Section 4(f) evaluation must be fully documented in the EIS (23 C.F.R. §§ 774.7, 774.9(b)).

The Supreme Court has made it clear that Section 4(f) resources must be given "paramount importance." *Citizens to Preserve Overton Park v. Volpe*, 401 U.S. 402, 412-13 (1971). The Draft EIS fails to do so:

- The Section 4(f) evaluation in the Draft EIS only covers the Project's direct use of historic resources within the physical footprint of Tinian International Airport (*see* Draft EIS at 4-537 to 4-545). The analysis must be expanded to include all potential direct and constructive uses associated with training activities that would not proceed but for an FAA approval.

- Although the section of the Draft EIS titled "Section 4(f) Evaluation" fails to identify all Section 4(f) resources or to properly evaluate their use, information gleaned from other portions of the document demonstrates that the Project will use ***at least*** the following: Unai Chulu, Unai Masalok, Unai Dankulo, Ushi Point, North Field, Regusa Beach, Apansanmena Beach, Shomshon Beach, *latte* sites on both Tinian and Pagan, conservation lands previously set aside within the Military Use Area on Tinian, and each of the resources in Draft EIS Appendix N, tables 27-39, that (i) would be impacted by the Project and (ii) is identified as eligible for listing in the National Register under Criterion A.

- As noted elsewhere in this Memorandum, the Draft EIS fails to address the existence, feasibility, or prudence of alternatives to the Project's severe impacts on historic resources.

c. Endangered Species Act

The ESA requires federal agencies, in consultation with the National Marine Fisheries Service ("NMFS") and/or the United States Fish and Wildlife Service ("USFWS"), to "insure that any action authorized, funded, or carried out by such agency…is not likely to jeopardize the continued existence of any endangered species or threatened species or result in the destruction or adverse modification of habitat for such species" (16 U.S.C. § 1536(a)(2)).

The Supreme Court has made it clear that these requirements establish a clear, judicially-enforceable mandate to halt and reverse the trend toward species extinction, ***whatever the cost***" (*Tennessee Valley Authority v. Hill*, 437 U.S. 153, 184 (1978) (emphasis added)). This mandate applies even where military training interests are at stake (*see, e.g., Conservation Council v. National Marine Fisheries Service*, 2015 U.S. Dist. Lexis 42226 (D. Hawaii 2015)).

In determining whether an action will impermissibly jeopardize the continued existence of any endangered or threatened species, agencies must consider whether the action "reasonably would be expected, directly or indirectly, to reduce appreciably the likelihood of both the survival and recovery of a listed species in the wild by reducing the reproduction, numbers, or distribution of that species" (50 C.F.R. § 402.02).

The Draft EIS fails to provide the information necessary for such an analysis (*see* parts 2 and 3 of this Memorandum). However, the limited information provided in sections 4.9 and 4.10 of the document confirms that the Project will, in fact, impermissibly jeopardize the existence of several endangered and threatened species, including the Mariana Moorhen, the Micronesian Megapode, the Mariana Fruit Bat, multiple species of sea turtles, and several species of corals.

The Navy must also take into account (i) USFWS' recent decision to list 23 species of plants and animals on Guam and the CNMI as threatened or endangered (*see* **Exhibit M**) and (ii) additional species for which petitions for listing have been submitted (*see* **Exhibit N**).

d. Marine Mammal Protection Act

The MMPA strictly prohibits all harassment, capture, or killing of marine mammals — even for "military readiness" — unless such activity can be demonstrated to have a "negligible impact" on the affected "population or stock" (16 U.S.C. §§ 1361(2), 1371(a)(5)(A)(i), 1371(a)(5)(F)). In complying with this mandate, agencies must use the "best scientific evidence available" (50 C.F.R. §216.102(a)).

The Draft EIS admits that protected marine mammals have been observed in the waters around Tinian and Pagan. But it fails to provide information necessary to demonstrate compliance with the MMPA:

- The Draft EIS does not consider the impacts of the CJMT on affected stocks of marine mammals (as distinguished from impacts evaluated at the species level).
- The Draft EIS purports to evaluate the *significance* of the Project's impacts on marine resources (Draft EIS at 4-264 to 4-326). It fails to apply the stricter "negligible impact" standard mandated by the MMPA (*id*.; *see also Conservation Council*, 2015 U.S. Dist. Lexis 42226 at *21).
- The Draft EIS does not provide data sufficient to meet the "best scientific evidence available" standard set forth in 50 C.F.R. §216.102(a).
- To the extent the Draft EIS acknowledges the MMPA, it is only in the context of amphibious training on Tinian (*see* Draft EIS at 1-23). The MMPA applies equally to the activities proposed for Pagan. Those activities include amphibious assault training, ship-to-shore bombardment, and significant shipping traffic related to logistics (*see* Draft EIS at 2-18 to 2-19, 2-121 to 2-125, 2-137 to 2-145), all of which have the potential to result in harassment, capture, or killing of protected marine mammals.

6. Conclusion and Remedy

The legal deficiencies set forth above render the Navy's Draft EIS so inadequate as to preclude meaningful analysis of the CJMT (40 C.F.R. § 1502.9). As such, the Draft EIS must be thoroughly revised and recirculated for a second round of public review before the Navy can proceed to a Final EIS (*id*.). If the Navy fails to take these steps, it will not have a legally-adequate basis for reaching a decision on the CJMT.

EXHIBIT A

REUTERS

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U.S. to bolster air, navy activity in northern Australia - source

Tue Aug 12, 2014 6:51am GMT

SYDNEY (Reuters) - The United States will bolster its air and navy presence in northern Australia, a source said on Tuesday, under a plan to strengthen defence ties with its regional ally and project more power into the Asia-Pacific, where China's influence is growing.

U.S. Defense Secretary Chuck Hagel and Secretary of State John Kerry are in Sydney to finalise an agreement reached between U.S. President Barack Obama and Australian Prime Minister Tony Abbott on the deployment of U.S. marines to Australia for joint exercises and training.

Some 1,150 Marines are stationed in Darwin in Australia's tropical north under a 2011 agreement that launched Obama's "pivot" to Asia.

The contingent, primed to respond to regional conflicts and humanitarian crises, will swell to 2,500 by 2017.

Officials were also finalising an agreement to boost U.S. air and naval activity in sparsely populated and resource-rich northern Australia with an increased tempo of visits by U.S. fighter jets and bombers, said a source with direct knowledge of the discussions.

"So more U.S. air force visits to northern Australia, where they can use the fabulous Delamere bombing range and they would probably base out of Tindal," the source said, referring to an Australian air force base in the Northern Territory.

The U.S.-Australia meetings will include discussions on cooperation in missile defence, cyber security and maritime security, Hagel told reporters at a briefing with Australian counterpart David Johnston on Monday.

Details of the Force Posture Agreement will be released later on Tuesday.

Hagel said the United States was firmly committed to its policy of a strategic rebalance to the Asia-Pacific region, something that has irked China and been questioned by allies who wonder about the extent of U.S. commitment to the region.

China has resisted what it sees as U.S. meddling in the region, particularly in the disputed East and South China Seas, and an attempt to contain its growing military, economic and political influence.

A U.S. proposal for a freeze on provocative acts in the South China Sea got a cool response from China and some Southeast Asian nations at a regional meeting at the weekend, an apparent setback to U.S. efforts to thwart China's assertive moves.

(Reporting by Lincoln Feast; Editing by Paul Tait)

EXHIBIT B

US, Australia sign military cooperation pact

By LOLITA C. BALDOR - *Associated Press - Tuesday, August 12, 2014*

SYDNEY (AP) - The U.S. and Australia signed an agreement Tuesday that will allow the two countries' militaries to train and work better together as U.S. Marines and airmen deploy in and out of the country.

"This long-term agreement will broaden and deepen our alliance's contributions to regional security," U.S. Defense Secretary Chuck Hagel said Tuesday. He described the U.S.-Australia alliance as the "bedrock" for stability in the Asia-Pacific region.

Hagel spoke during a press conference with U.S. Secretary of State John Kerry and their Australian counterparts, Foreign Minister Julie Bishop and Defense Minister David Johnston, at the conclusion of annual Australia-U.S. strategic talks.

Kerry praised Australia as "a vital partner in so many different endeavors."

When President Barack Obama visited Australia in 2011, he fueled tensions with China, Australia's biggest trading partner, by announcing that up to 2,500 U.S. Marines would rotate through a joint military training hub in the northern Australian city of Darwin.

The Marines conduct humanitarian and military exercises with Australian forces.

Since 2011, the number of Marines there has grown from about 250 to more than 1,100 now. Australian Defense Minister David Johnston said the northern territory looks forward to the Marine presence growing to the 2,500 limit.

Adm. Sam Locklear, who heads U.S. Pacific Command, told reporters Monday that there is no timeline for the increase to 2,500.

The 2,500, said Locklear, is the size of a Marine air/ground task force unit, which "gives us the best flexibility to partner with" Australia and other allies in the region.

One U.S. official said it will take several years to reach the full 2,500-troop level. That official was not authorized to speak publicly about the timeline and requested anonymity.

EXHIBIT C

Exercise TALISMAN SABRE 2015 is a biennial combined Australian and United States (US) training activity, designed to train our respective military forces in planning and conducting Combined Task Force operations to improve the combat readiness and interoperability between our respective forces. This exercise is a major undertaking that reflects the closeness of our alliance and the strength of the ongoing military-military relationship.

What is Exercise Talisman Sabre?

The Talisman Sabre series of exercises is a major Australian and United States military training exercise focused on the planning and conduct of mid-intensity "high end" warfighting. This will be the sixth time the Exercise has been conducted and will involve up to 30,000 Australian and US defence personnel.

TS15 will incorporate force preparation activities, Special Forces activities, amphibious landings, parachuting, land force manoeuvre, urban operations, air operations, maritime operations and the coordinated firing of live ammunition and explosive ordnance from small arms, artillery, naval vessels and aircraft.

Where will TS15 take place?

This year marks the first time Exercise Talisman Sabre has run simultaneously within the Shoalwater Bay Training Area, near Rockhampton in Central Queensland and at Fog Bay, south west of Darwin.

Tweets Follow

TalismanSabre @TalismanSabre 21 Jul
Ex #TS15 concludes aboard @USSBlueRidge. navy.mil/submit/display...
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U.S. Pacific Fleet @USPacificFleet 21 Jul
Exercise @TalismanSabre concludes with ceremony aboard USS Blue Ridge in #Brisbane 1.usa.gov/1DsOChz
Retweeted by TalismanSabre
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TalismanSabre @TalismanSabre 21 Jul
Ex #TS15 videos produced by US & Aus military videographers can be found here: bit.ly/1LzGwdv #ADFonEX #YourADF #PacificCommand
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Amphibious Warships @amphibwarships 20 Jul
After 2 weeks, command ship USS Bonhomme Richard completes exercise @TalismanSabre bit.ly/1SxDCX2 #TS15 pic.twitter.com/kbF07AOGey
Retweeted by TalismanSabre

Tweet to @TalismanSabre

The Australian Army will be staging Exercise Hamel in conjunction with TS15 at Shoalwater Bay using Talisman Sabre themes and scenarios.

When is it being held?

TS15 is scheduled to take place early to mid-July 2015. The Exercise itself will take place over approximately 20 days, with Force preparation and demobilisation activities carried out in the weeks leading up to and after the Exercise.

How are the communities being involved?

Defence has been working closely with the communities of Darwin and Fog Bay for more than a year. The Rockhampton community is more used to hosting defence activity but they too are being consulted, particularly in relation to environmental safeguards which will be put in place.

Defence is taking all necessary steps to safeguard the environment during Talisman Sabre 15. The ADF protects endangered species and marine mammals through a comprehensive framework of risk mitigation procedures developed after careful analysis of all Defence maritime activities.

Where can I find more on Defence's efforts to safeguard the environment during this activity?

Public submissions have now closed but interested community members are encouraged to view the draft Public Environment Report (http://www.aecom.com/Where+We+Are/Australia+-+New+Zealand/Publications/Talisman+Sabre/Talisman+Sabre+2015).

Defence is proud of its environmental management record throughout past exercises and the day-to-day management of all its training sites, which has been demonstrated through the collection of key environmental data.

How is TALISMAN SABER 2015 being environmentally assessed?

A draft Public Environment Report has been prepared by consultants to Defence, Aurecon, to inform Defence, the Australian public and relevant stakeholders of potential environmental and heritage issues relating to the conduct of TALISMAN SABER 13.

All interested community members are encouraged to view the draft Public Environment Report and provide feedback during the public consultation period from 24 September to 26 October 2012. Copies of the draft report as well as supporting fact sheets can be downloaded from http://www.aurecongroup.com/talismansabre2013 (http://www.aurecongroup.com/talismansabre2013).

EXHIBIT D

Japan will join a major U.S.-Australian military exercise for the first time in a sign of growing security links between the three countries as tensions fester over China's island building in the South China Sea.

While only 40 Japanese officers and soldiers will take part in drills involving 30,000 U.S. and Australian troops in early July, experts said the move showed how Washington wanted to foster cooperation among its security allies in Asia.

The Talisman Sabre biennial exercises, to be held in locations around Australia, will encompass maritime operations, amphibious landings, special forces tactics and urban warfare.

"I think the U.S. is trying to get its allies to do more," said Euan Graham, director of the International Security Program at the Lowy Institute in Sydney.

"There is an obvious symmetry between Japan as the upper anchor of the Western Pacific alliance and ... Australia as the southern anchor."

All three nations have said they were concerned about freedom of movement through the seas and air in the disputed South China Sea, where China is creating seven artificial islands in the Spratly archipelago, a vital shipping corridor.

Some security experts say China might impose air and sea restrictions in the Spratlys once it completes construction work that includes at least one military airstrip. China has said it had every right to set up an Air Defence Identification Zone but that current conditions did not warrant one.

China claims most of the South China Sea. The Philippines, Vietnam, Malaysia, Taiwan and Brunei also have overlapping claims.

The Japanese personnel will embed with U.S. forces while 500 New Zealand troops will join Australian contingents, according to the Australian Defence Force website.

Japanese Defense Minister Gen Nakatani rebuffed suggestions the exercises were aimed at China, telling Reuters that Japan simply wanted to improve military cooperation with the United States and Australia.

China's Foreign Ministry spokeswoman Hua Chunying, asked if Beijing was concerned the exercises appeared to be targeted toward China, said it was "not worried".

"We believe the relevant countries should all play a proactive and constructive role to strengthen mutual trust and cooperation between countries in the region," she said at a regular news briefing.

"UNPRECEDENTED TRILATERAL COOPERATION"

Security cooperation between Canberra and Tokyo has already flourished under Prime Ministers Tony Abbott and Shinzo Abe, with Japan seen as the frontrunner to win a contract to supply next generation submarines to the Australian navy. U.S. commanders have publicly supported such a tie-up.

U.S. Assistant Secretary of Defense David Shear highlighted Washington's goal of boosting cooperation between its allies in testimony to the U.S. Senate this month.

"To expand the reach of these alliances, we are embarking on unprecedented trilateral cooperation," he said.

"In some cases this cooperation directly benefits our work on maritime security. For example, we're cooperating trilaterally with Japan and Australia to strengthen maritime security in Southeast Asia and explore defense technology cooperation."

Winning the submarine deal would be a big boost for Japan's defense industry and potentially pave the way for the sale of advanced Japanese weapons to countries such as the Philippines and Vietnam, which are at loggerheads with Beijing over the South China Sea, experts have said.

Australia also hopes to sign a deal with Japan this year that would smooth the passage of military personnel into one another's country for joint exercises, the Sydney Morning Herald newspaper reported over the weekend.

Deals such as this would likely become more common as Abbott and Abe push to cement the security ties they have fostered before they leave office, said the Lowy Institute's Graham.

"There will be more of this, and it's important in the next couple of years that the relationship beds in because otherwise ... you could quickly find it isn't a self-sustaining relationship," he said.

(Additional reporting by Nobuhiro Kubo in TOKYO and Michael Martina in BEIJING; Editing by Dean Yates)

EXHIBIT E

theguardian

Philippines agrees to 10-year pact allowing US military presence

Defense accord would let US military return to south-east Asian nation amid increasing tensions with China over territory

Associated Press in Manila

Sunday 27 April 2014 09.59 EDT

The United States and the Philippines have reached a 10-year pact that would allow a larger US military presence in this south-east Asian nation as it grapples with increasingly tense territorial disputes with China, White House officials said on Sunday.

Two Philippine officials confirmed the agreement to the Associated Press before the White House announcement.

The Enhanced Defense Cooperation Agreement would give American forces temporary access to selected military camps and allow them to preposition fighter jets and ships. It will be signed on Monday at the Department of Defense in the Philippine capital, Manila, before President Barack Obama arrives on the last leg of a four-country Asian tour, following earlier stops in Japan, South Korea and Malaysia.

A Philippine government primer on the defense accord that was seen by the AP did not indicate how many additional US troops would be deployed "on temporary and rotational basis", but it said that the number would depend on the scale of joint military activities to be held in Philippine camps.

The size and duration of that presence still has to be worked out with the Philippine government, said Evan Medeiros, senior director for Asian affairs at the White House's National Security Council.

Medeiros declined to say which specific areas in the Philippines are being considered under the agreement, but said the long-shuttered US facility at Subic Bay could be one of the locations.

The two Philippine officials spoke with the AP on condition of anonymity because they were not authorized to discuss details of the pact before it is signed.

The defense accord is a new milestone in the longtime treaty allies' relationship and would help address their respective dilemmas. The Philippines has struggled to bolster its territorial defence amid China's increasingly assertive behaviour in the disputed

South China Sea. Manila's effort has dovetailed with Washington's intention to pivot away from years of heavy military engagement in the Middle East to Asia, partly as a counterweight to China's rising clout.

"The Philippines' immediate and urgent motivation is to strengthen itself and look for a security shield with its pitiful military," Manila-based political analyst Ramon Casiple said. "The US is looking for a re-entry to Asia, where its superpower status has been put in doubt."

The convergence would work to deter China's increasingly assertive stance in disputed territories, Casiple said. But it could also further antagonize Beijing, which sees such tactical alliance as a US strategy to contain its rise, and encourage China to intensify its massive military buildup, he said.

Hundreds of American military personnel have already been deployed in the southern Philippines since 2002 to provide counterterrorism training and to serve as advisers to Filipino soldiers, who have been battling Muslim militants for decades.

The agreement states that the US would "not establish a permanent military presence or base in the Philippines" in compliance with Manila's constitution. A Filipino base commander would have access to entire areas to be shared with American forces, according to the primer. There will be "utmost respect for Philippine sovereignty", it said.

Disagreements over Philippine access to designated US areas within local camps had hampered the negotiations for the agreement last year.

The agreement would promote better coordination between US and Filipino forces, boost the 120,000-strong Philippine military's capability to monitor and secure the country's territory and respond more rapidly to natural disasters and other emergencies.

"Pre-positioned material will allow for timely responses in the event of disasters natural or otherwise," the primer said.

While the US military would not be required to pay rent for local camp areas, the Philippines would own buildings and infrastructure to be built or improved by the Americans and reap economic gains from the US presence, it said, adding the pact was an executive agreement that would not need to be ratified by the Philippine Senate.

The presence of foreign troops is a sensitive issue in the Philippines, a former American colony.
Left-wing activists have protested against Obama's visit and the new defense pact in small but lively demonstrations, saying that the agreement reverses democratic gains achieved when huge US military bases were shut down in the early 1990s, ending nearly a century of American military presence in the Philippines.

The Philippine Senate voted in 1991 to close down US bases at Subic and Clark, northwest of Manila. However, it ratified a pact with the United States allowing temporary visits by American forces in 1999, four years after China seized a reef the Philippines contests.

Following the September 11 attacks in the United States, hundreds of US forces descended in the southern Philippines under that accord to hold counterterrorism exercises with Filipino troops fighting Muslim militants.

This time, the focus of the Philippines and its underfunded military has increasingly turned to external threats as territorial spats with China in the potentially oil- and gas-rich South China Sea heated up in recent years. The Philippines has turned to Washington, its longtime defense treaty ally, to help modernize its navy and air force, which are among Asia's weakest.

Chinese paramilitary ships took effective control of the disputed Scarborough Shoal, a rich fishing ground off the northwestern Philippines, in 2012. Last year, Chinese coast guard ships surrounded another contested offshore South China Sea territory, the Second Thomas Shoal, where they have been trying to block food supplies and rotation of Filipino marines aboard a grounded Philippine navy ship in the remote coral outcrops. The dangerous standoff has alarmed Washington, which called China's actions provocative.

China has ignored Philippine diplomatic protests and Manila's move last year to challenge Beijing's expansive territorial claims in the South China Sea before an international arbitration tribunal. It has warned the US to stay out of the Asian dispute.

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EXHIBIT F

Thousands of Philippine and American soldiers began annual war games on Monday near disputed waters in the South China Sea, testing the readiness of the two oldest security allies in the southeast Asian region to respond to any emergency.

The Philippines has territorial disputes with China over the South China Sea, which is said to be rich in energy deposits and carries about $5 billion in ship-borne trade every year. The Spratlys in the South China Sea are also claimed by Brunei, Malaysia, Taiwan and Vietnam.

Nearly 5,000 U.S. and Filipino troops will participate in the 11-day annual exercise, to be held in the Philippines' western island of Palawan, near the Spratlys, and in the northwest province of Zambales on the main island of Luzon, just 100 miles (160 km) off Scarborough Shoal.

The joint air and marine exercises "Philippine Bilateral Exercises," or Phiblex, will focus more closely on maritime security and territorial defense operations as China continues to step up its presence and activities in the region.

"We're hoping to gain new techniques from the U.S. marine corps," Captain Reyson Talingdan, head of the public affairs of the Philippines' 3rd Marine Brigade in Palawan, told reporters.

"If they have new doctrines, we'll be able to learn from them."

Two U.S. amphibious ships, USS Peleliu and USS Germantown, are participating in the exercises. Besides simulating boat raids and beach assaults, they will feature aerial live fire, mechanized armor maneuvers and parachute drops.

"The field training exercises will provide the Philippines and U.S marine units multiple opportunities to continue to improve their skills while sharing best practices and enhancing an already high level of cohesion," the U.S. embassy said in a statement.

The military reported Beijing continued its reclamation work in four areas in the Spratlys despite the southwest monsoon.

China has expanded its territory in the Gaven, Johnson South, Cuarteron and Chigua reefs in the Spratlys, reclaiming land to build islands to assert its claims.

The Philippines has monitored the presence of more than 120 Chinese warships and fishing boats in the Spratlys in the first half of 2014, establishing firm control over disputed areas.

China seized control of Scarborough Shoal, a rocky outcrop north of the Spratlys, in June 2012 after a three-month standoff with the Philippines, denying Filipino fishermen access to the rich fishing ground.

In the Scarborough Shoal, the Philippines has also reported the presence of an increasing number of ships, from 11 in the last quarter of 2013 to 34 in the first quarter this year.

The annual drills between Philippine and U.S. forces are being held under the 1951 Mutual Defence Treaty (MDT), part of a web of security alliances the United States built in the Asia-Pacific region during the Cold War.

(Reporting by Manuel Mogato; Editing by Clarence Fernandez)

EXHIBIT G

Tinian mayor: Redo flawed EIS

San Nicolas demands 'environmental justice'

By Dennis B. Chan | Posted on Sep 25 2015

Tag: DEIS, DOD, people, San Nicolas

Tinian Mayor Joey Patrick San Nicolas released yesterday a letter sent to the U.S. military, arguing its failures in analyzing the impact of proposed live-fire training on Tinian. The letter calls all military training alternatives on Tinian an end to economic viability, destruction of land and resources, and a denial of the Tinian's people right to live in a safe and healthy environment.

The letter—sent on Sept. 14 as part of the comment period for the National Environmental Policy Act—formalizes and reiterates Tinian's concerns over the military's proposal.

The Marine Corps Forces Pacific has laid out plans for four range complexes on Tinian inclusive of grenade, tank, pistol, and mortar training, and restricted airspace. They plan to build on land they lease—the northern two-thirds of Tinian.

But San Nicolas says this activity would be an "economic chokehold" on Tinian, noting its growing tourism industry, and denial of customary and traditional rights as live-fire operations would limit access to gathering and fishing sites.

San Nicolas is also concerned at the apparent lack of mitigation for the construction and operation of live-fire ranges. Up to 3,000 personnel will be on Tinian during operations phase, essentially doubling the island's population during these times. DoD says this will cause "no significant impact"

In a nutshell, the letter describes "legal deficiencies" with the CNMI Joint Military Training EIS and demands that the military rethink its plans.

"Let us be clear: the people of Tinian oppose and will continue to oppose any plans to carry out the training described in the CJMT EIS. We will do everything that we can—legally, politically, and socially—to protect our families, our culture, and our island."

San Nicolas demands that the Department of Defense:

Provide the people of Tinian with an accurate assessment of environmental justice concerns;

Prepare a single environmental impact statement that addresses all connected and cumulative actions that will impact the island of Tinian and the CNMI;

WEATHER FORECASTS

Saipan, Northern Mariana Islands

CURRENT CONDITIONS FOR SAIPAN AS OF MON, 28 SEP 2015 11:01 PM CHST

28°

Cloudy High: 30° Low: 26°

Feels like: 28 °C
Barometer: 982.05 mb and steady
Humidity: 94%
Visibility: 16.09 km
Dewpoint: 26 °C
Wind: 24.14 km/h
Sunrise: 6:05 am
Sunset: 6:09 pm

POWERED BY YAHOO! WEATHER

POLL

Sorry, there are no polls available at the moment.

Correct a flawed discussion with regards to alternatives discussed in the DEIS;

Comply with the National Historic Preservation Act;

Adequately assess the impacts to endangered species as required by the Endangered Species Act; and

Adequately assess the impact to marine mammals required by the Marine Mammals Protection Act.

Marianas Forces Pacific was sent a request for comment but Saipan Tribune did not receive a response as of press time.

Environmental justice

San Nicolas argues that the military's plans—as laid out in the EIS—fails on a level of environmental justice, falling short of even acknowledging these issues as coherent, or salient, and incorrectly dismissing impacts that would seem prevalent and clear to the people on the island.

San Nicolas notes a presidential directive—an executive order from the White House in 1994—that tasks federal agencies to safeguard how their proposed actions affect minority populations, low-income populations, and indigenous peoples.

That directive, Executive Order 12898, tasks federal agencies to identify and address "disproportionately high and adverse human health or environmental effects of its programs, policies, and activities on minority populations and low-income populations in the United States and its territories and possessions, the District of Columbia, the Commonwealth of Puerto Rico, and the Commonwealth of the Mariana Islands."

San Nicolas cites records and the EIS to say that 98 percent of the people on Tinian are minorities, and how 44 percent of the population is "low income

San Nicolas says Defense has taken the position in their impact statement that because all of Tinian is considered a minority and low-income area, there are no environmental justice issues.

As an example, San Nicolas cites the DEIS in saying that over 1,000 people on Saipan and Tinian will be exposed to noise levels of 115 decibels during 10 percent to 15 percent of the total training time proposed under CJMT. This noise level is comparable to the sound of the siren on an emergency vehicle, a firework, or "being near a rock band," San Nicolas said, citing the EIS.

The residents affected by these impacts live in minority and low-income areas, San Nicolas said, but the DEIS "then incredibly concludes that the impact would not be considered disproportional as all of the CNMI is considered a minority and low-income area."

"DOD's inane interpretation of environmental justice is that if an action affects only minority and low-income populations, there is no disproportionate impact," San Nicolas writes. "Therefore, DOD can claim that there [are] no environmental justice issues to analyze. DOD's policy appears to encourage targeting islands and areas that are comprised solely of minority populations, low-income populations, and indigenous peoples."

San Nicolas notes that the DEIS details cumulative impact on soil, noise pollution, airspace, land and submerged lands use, recreational resources, terrestrial biology, marine biology, visual resources, cultural resources, socioeconomics, and environmental justice.

"In the CNMI, it will be the people of Tinian that will disproportionately have to bear the significant impacts of the proposed activities as all the alternatives involve the use of Tinian... The impacts of the CJMT would fall disproportionately on the islands Tinian and Pagan."

Inconsistent statements

San Nicolas says DoD has lacked transparency in its outreach.

Citing an earlier Saipan Tribune article in June, San Nicolas quotes Marforpac executive director Craig Whelden saying that there would not be a "bombing range."

Whelden said then that DoD has "also consistently said that high hazard impact area would be limited to the volcanic area in the north, thereby protecting and reserving flora and fauna." But expanding on this "high hazard area," San Nicolas cites the EIS, which notes 175 2,000-lb aviation ordnance, 175 1,000-lb aviation ordnance, and 175 500-lb aviation ordnance that would be dropped on Pagan every year.

"It is the inconsistency between statements made by DOD representatives and the actual DEIS that have created confusion over what exactly DOD's plans are in the CJMT. It is also the reason why many people in the CNMI have come to doubt the credibility of the DOD officials who have been handling the NEPA process. When DOD prepares another EIS, it should make a real effort to obtain input from the local community in the decision-making process, employ a strategy that encourages public participation rather than simply going through the motions, and be transparent about the planned actions and impacts," San Nicolas said.

Bigger, connected picture

San Nicolas's letter also draws a picture of the cumulative and connected impacts of several DoD projects that he believes DoD has failed to combine and analyze for the public together.

This failure frustrates the ability of the community to analyze and comment on the impacts of these actions on Tinian and the Mariana Islands as a whole, San Nicolas said.

Citing Council for Environmental Quality regulations, San Nicolas says all "connected actions" must be considered in a single EIS. These are the Guam-CNMI relocation, CJMT, and Marianas Islands Training and Testing, or MITT EIS which all purport impacts to Tinian.

San Nicolas notes that the notice of intent for the MITT EIS, which described expansive sonar, undersea, and bombing training, was issued in September 2011, and expanded on an earlier EIS, the Marianas Islands Range Complex.

The MITT draft was released in September 2013, or six months after DOD filed the notice intent for the CJMT. The final MITT EIS was released in May 2015, San Nicolas said.

"It is evident from the record that DOD was planning all of these actions simultaneously, but elected to release three separate EIS's and conduct three separate NEPA processes rather than preparing a single document," San Nicolas said.

Dennis B. Chan | Reporter

Dennis Chan covers education, environment, utilities, and air and seaport issues in the CNMI. He graduated with a degree in English Literature from the University of Guam. Contact him at dennis_chan@saipantribune.com.

« *Previous Story* $145M budget heads to Inos

Next Story »

EXHIBIT H

Commonwealth Ports Authority - Airport Division
FAA AIP Grant Listing
2000 to 2015

	AIP No.	Description	Date Of Award	Grant Amount	Amendments	Total FAA Funding	Share Agreement
Saipan							
	3-69-0002-31	Runway Rehab Phase I	Sept. 01, 2000	2,374,254.00	0.00	2,374,254.00	100%FAA
	3-69-0002-32	Runway Rehab Phase II	Aug. 30, 2001	3,956,095.00	0.00	3,956,095.00	90% FAA - 10% CPA
	3-69-0002-33	ARFF Training Facility	June 14, 2001	2,946,079.00	0.00	2,946,079.00	90% FAA - 10% CPA
	3-69-0002-34	3,000 Gallon ARFF Vehicle	June 17, 2001	645,000.00	0.00	645,000.00	100% FAA
	3-69-0002-35	Perimeter Fencing	June 14, 2001	1,641,541.00	0.00	1,641,541.00	90% FAA - 10% CPA
	3-69-0002-36	Security Improvements	April 5, 2002	294,173.00	0.00	294,173.00	100% FAA
	3-69-0002-37	Noise Mitigation	August 19, 2012	900,000.00	0.00	900,000.00	90% FAA - 10% CPA
	3-69-0002-38	Security Enhancement Phase I	Sept. 26, 2002	5,346,000.00	801,900.00	6,147,900.00	90% FAA - 10% CPA
	3-69-0002-40	Security Improvements	September 26, 2002	294,172.00		294,172.00	100% FAA
	3-69-0002-41	Security Enhancement Phase II	Sept. 27, 2002	1,500,000.00	225,000.00	1,725,000.00	100% FAA
	3-69-0002-42	Terminal Roof Replacement-Phase I	Aug. 7, 2003	1,000,000.00	150,000.00	1,150,000.00	100% 1st 460K 90% after
	3-69-0002-43	Rehabilitate Apron/Taxiline-Phase III	Aug. 7, 2003	2,000,000.00	0.00	2,000,000.00	90% FAA - 10% CPA
	3-69-0002-44	Passenger Lift Device	August 26, 2002	100,000.00	0.00	100,000.00	100% FAA
	3-69-0002-45	Airport Runway Safety Area Improve	Aug. 7, 2003	3,600,000.00	0.00	3,600,000.00	90% FAA - 10% CPA
	3-69-0002-46	ARFF Training Facility Construction Phase III	August 21, 2003	1,000,000.00		1,000,000.00	90% FAA - 10% CPA
	3-69-0002-47	Terminal Roof Replacement-Phase II	Jun. 25, 2004	3,000,000.00	450,000.00	3,450,000.00	100% 1st 2M 95% after
	3-69-0002-48	Terminal Building Loading Bridge-2 ea.	Jun. 25, 2004	1,300,000.00	0.00	1,300,000.00	95% FAA - 5% CPA
	3-69-0002-49	Improve Runway 7/25 Safety Area Phase II	Jun. 25, 2004	4,000,000.00	0.00	4,000,000.00	95% FAA - 5% CPA
	3-69-0002-50	Rehabilitate Runway 7/25-Phase III	Jun. 25, 2004	5,000,000.00	0.00	5,000,000.00	95% FAA - 5% CPA
	3-69-0002-51	ARFF Vehicle/Typhoon Chaba Repairs	Aug. 24, 2004	1,965,462.00	0.00	1,965,462.00	95% FAA - 5% CPA
	3-69-0002-52	Expand Terminal Building (Design & CM)	August 17, 2005	2,510,103.00	0.00	2,510,103.00	95% FAA - 5% CPA
	3-69-0002-53	Rehabilitate Runway 7/25-Phase IV	Aug. 26, 2005	5,000,000.00	0.00	5,000,000.00	100% 1st 4M 95% after
	3-69-0002-54	Expand ARFF Building - (Design Only)	Aug. 26, 2005	500,000.00	0.00	500,000.00	95% FAA - 5% CPA
	3-69-0002-55	Terminal Bldg Expans./Loading Bridge II	Aug. 21, 2006	3,490,413.00	5,000,000.00	8,490,413.00	100% 1st 4M 95% after
	3-69-0002-56	Rehabilitate Taxilane C - Phase IV	Aug. 21, 2006	2,000,000.00		2,000,000.00	100% 1st 509,587 95% after
	3-69-0002-57	Emergency Generator/Procurement/Install	Jun. 12, 2008	2,100,000.00	315,000.00	2,415,000.00	100% FAA

3-69-0002-58	Rehabilitate Runway 7/25 - Phase V	Jun. 12, 2008	1,828,434.00	274,265.00	2,102,699.00	100% FAA
3-69-0002-59	Acquire Emergency Generator - Phase II	Feb. 27, 2009	2,317,898.00	347,685.00	2,665,583.00	100% FAA
3-69-0002-60	Rehabilitate Runway 7/25 - Phase VI	Aug. 31, 2009	5,000,000.00		5,000,000.00	100% FAA
3-69-0002-61	Acquire Emergency Generator - Phase III	Aug. 13, 2009	1,885,902.00	240,338.00	2,126,240.00	100% 1st $1,682,102 95% after
3-69-0002-62	Improve Terminal Building	Aug. 13, 2009	2,197,034.00		2,197,034.00	95% FAA - 5% CPA
3-69-0002-63	Rehabilitate Runway 7/25 - Phase VII	Aug. 31, 2009	3,200,000.00	480,000.00	3,680,000.00	95% FAA - 5% CPA
3-69-0002-64	Rehabilitate Runway 7/25 - Phase VII	Mar. 31, 2010	1,000,000.00	150,000.00	1,150,000.00	95% FAA - 5% CPA
3-69-0002-65	Improve Terminal Building - Phase II	Mar. 31, 2010	1,536,634.00		1,536,634.00	95% FAA - 5% CPA
3-69-0002-66	Rehabilitate Taxiway C - Phase V	Jul. 22, 2010	258,476.00		258,476.00	100% FAA
3-69-0002-67	Improve Terminal Building - Phase III	Jul. 22, 2010	1,266,332.00	-194,359.00	1,071,973.00	100% FAA
3-69-0002-68	ARFF Training Facility Phase I - Design Only	Jul. 27, 2010	1,000,000.00		1,000,000.00	100% FAA
3-69-0002-69	ARFF Training Facility Phase II - Construction	Aug. 17, 2010	4,800,000.00		4,800,000.00	100% 1st 1,475,192-95% after
3-69-0002-70	Rehabilitate Runway 7/25 - Phase IX	Mar. 13, 2011	2,206,874.00	331,031.00	2,537,905.00	100% FAA
3-69-0002-71	Rehabilitate Runway 7/25 - Phase X	Sep. 02, 2011	2,574,512.00		2,574,512.00	100% 1st$1,793,126-95% after
3-69-0002-72	ARFF Training Facility Phase III - Construction	Sep. 15, 2011	6,000,000.00	900,000.00	6,900,000.00	95% FAA - 5% CPA
3-69-0002-73	Rehabilitate Runway 7/25 - Phase XI	Jul. 19, 2012	8,034,600.00		8,034,600.00	100% 1st$2,000,000-90% after
3-69-0002-74	ARFF Training Facility Phase IV - Construction	Sep. 05, 2012	3,900,000.00		3,900,000.00	90% FAA/10% CPA
3-69-0002-75	Rehabilitate Runway 7/25 - Phase XII	Sept. 19, 2012	6,000,000.00		6,000,000.00	90% FAA/10% CPA
3-69-0002-76	1,500 Gallon ARFF Vehicle	Aug. 23, 2013	794,025.00		794,025.00	90% FAA/10% CPA
3-69-0002-77	ARFF Training Facility Phase V - Construction	Aug. 23, 2013	2,311,042.00		2,311,042.00	100% 1st$2,000,000-90% after
3-69-0002-78	Improve Terminal Building - Phase IV	August 11, 2014	2,885,179.00		2,885,179.00	100% 1st$2,000,000-90% after
3-69-0002-79	Taxiway "B" Rehab Phase I (Design Grant)	August 11, 2014	175,000.00		175,000.00	90% FAA/10% CPA
3-69-0002-80	Procurement Runway Sweeper	August 11, 2014	420,000.00		420,000.00	90% FAA/10% CPA
3-69-0002-81	Runway Rehab 07/25 Phase XIII	August 11, 2014	376,225.00		376,225.00	90% FAA/10% CPA
3-69-0002-82	ARFF Training Facility Impr - Phase VI	August 11, 2014	671,101.00		671,101.00	90% FAA/10% CPA
3-69-0002-83	Taxiway "B" Rehab Phase I (Construction Grant)	August 24, 2015	1,000,000.00		1,000,000.00	100% FAA
3-69-0002-84	ARFF Training Facility Impr - Phase VII	July 13, 2015	1,052,135.00		1,052,135.00	100% 1st$1,000,000-90% after
3-69-0002-85	1,500 Gallon ARFF Vehicle	August 24, 2015	700,000.00		700,000.00	90% FAA - 10% CPA
3-69-0002-86	Improve Terminal Building Phase V	July 13, 2015	701,554.00		701,554.00	90% FAA/10% CPA
			124,556,249.00	**9,470,860.00**	**134,027,109.00**	

Rota	AIP No.	Description	Date Of Award	Grant Amount	Amendments	Total FAA Funding	Share Agreement
	3-69-0003-11	Runway Grooving/Marking	February 7, 2001	450,000.00	0.00	450,000.00	100% FAA
	3-69-0003-12	Airport Master Plan Study Update	August 6, 2001	350,000.00	0.00	350,000.00	100% FAA
	3-69-0003-13	PAPI/REIL Installation	August 30, 2001	255,000.00	0.00	255,000.00	100% FAA
	3-69-0003-14	Environmnental Assessment for Runway 9/27	September 25, 2002	270,738.00	0.00	270,738.00	90% FAA/10% CPA
	3-69-0003-15	Terminal Building Repairs	February 5, 2003	340,000.00	51,000.00	391,000.00	100% FAA
	3-69-0003-16	1,500 Gallon ARFF Vehicle	August 7, 2003	600,000.00	64,445.00	664,445.00	100% FAA
	3-69-0003-17	Passenger Lift Device	August 7, 2003	250,000.00	18,102.00	268,102.00	100% FAA
	3-69-0003-18	Typhoon Chaba Repairs - (Terminal Bldg)	Aug. 27, 2004	331,311.00	31,311.00	362,622.00	95% FAA - 5% CPA
	3-69-0003-19	Extended Runway 9/27	Aug. 24, 2005	5,000,000.00		5,000,000.00	95% FAA - 5% CPA
	3-69-0003-20	Install Runway Lighting System-7/25	Jun. 12, 2008	5,700,000.00	855,000.00	6,555,000.00	95% FAA - 5% CPA
	3-69-0003-21	Grant Cancelled by FAA					
	3-69-0003-22	1,500 Gallon ARFF Vehicle	Aug. 23, 2013	833,315.00		833,315.00	90% FAA/10% CPA
	3-69-0003-23	Improve ARFF Bldg Phase I - Design	August 11, 2014	100,000.00		100,000.00	90% FAA/10% CPA
	3-69-0003-24	Runway Sweeper Procurement	August 24, 2015	360,000.00		360,000.00	90% FAA/10% CPA
	3-69-0003-25	Airport Master Plan Study Update	July 8, 2015	420,000.00		420,000.00	90% FAA/10% CPA
				15,260,364.00	**1,019,858.00**	**16,280,222.00**	

Tinian	AIP No.	Description	Date Of Award	Grant Amount	Amendments	Total FAA Funding	Share Agreement
	3-69-0011-10	Runway 8/26 Construction	June 29, 2000	4,150,000.00	622,500.00	4,772,500.00	90% FAA - 10% CPA
	3-69-0011-11	Airport Master Plan Study Update	August 6, 2001	300,000.00	0.00	300,000.00	100% FAA
	3-69-0011-12	Apron/Taxiway Construction	September 26, 2002	2,310,085.00	0.00	2,310,085.00	90% FAA - 10% CPA
	3-69-0011-13	1,500 Gallon ARFF Vehicle	September 26, 2002	540,000.00	53,256.00	593,256.00	90% FAA - 10% CPA
	3-69-0011-14	Passenger Lift Device	August 7, 2003	250,000.00	320,706.00	570,706.00	100% FAA
	3-69-0011-15	Parallel Taxiway Strengthening	Sept. 08, 2003	4,073,531.00	0.00	4,073,531.00	90% FAA - 10% CPA
	3-69-0011-16	Terminal Passenger Loading Bridge	Jul. 06, 2004	1,000,000.00	0.00	1,000,000.00	95% FAA - 5% CPA
	3-69-0011-17	Emergency Generator/Typ Chaba Repairs	Aug. 23, 2004	562,810.00	0.00	562,810.00	95% FAA - 5% CPA
	3-69-0011-18	Relocate ARFF Bldg-Phase I (Design)	Aug. 30, 2005	1,045,657.00	0.00	1,045,657.00	95% FAA - 5% CPA
	3-69-0011-19	Strengthen Parallel Taxiway - Phase II	Aug. 21, 2006	1,860,432.00	0.00	1,860,432.00	95% FAA - 5% CPA
	3-69-0011-20	Strengthen Parallel Taxiway - Phase III	August 9, 2007	1,684,647.00	0.00	1,684,647.00	95% FAA - 5% CPA
	3-69-0011-21	Strengthen Parallel Taxiway - Phase IV	Jun. 16, 2008	1,386,400.00	0.00	1,386,400.00	95% FAA - 5% CPA

	3-69-0011-22	1,500 Gallon ARFF Vehicle	Aug. 23, 2013	830,025.00	0.00	830,025.00	90% FAA/10% CPA
	3-69-0011-23	Utility Upgrade for Rapid Refill (Design/CM)	Pending	390,348.00	0.00	390,348.00	
	3-69-0011-24	Grant Cancelled by FAA					
	3-69-0011-25	Runway Sweeper Procurement	August 24, 2015	360,000.00	0.00	360,000.00	90% FAA/10% CPA
	3-69-0011-26	Airport Master Plan Study Update	July 8, 2015	420,000.00	0.00	420,000.00	90% FAA/10% CPA
				21,163,935.00	**996,462.00**	**22,160,397.00**	

	AIP No.	Description	Date Of Award	Grant Amount	Amendments	Total FAA Funding	Share Agreement
Pagan	3-69-0004-01	Pagan Conduct Airport Master Plan Study	Aug. 17, 2005	300,000.00	0.00	300,000.00	95% FAA - 5% CPA
				300,000.00	**0.00**	**300,000.00**	
						0.00	
			Total FAA Grant Funding Assistance	161,280,548.00	11,487,180.00	172,767,728.00	

EXHIBIT I

Pacific Islands Report
Pacific Islands Development Program, East-West Center
With Support From Center for Pacific Islands Studies, University of Hawai'i

0

Military, Civilian Aircrafts Nearly Collide In CNMI
'Unannounced' C-130s come within 300 feet of twin-engine plane

By Dennis B. Chan

SAIPAN, CNMI (Saipan Tribune, March 3, 2015) – Military and civilian aircraft came disturbingly close last Wednesday afternoon in the skies between Saipan and Tinian.

According to documents obtained by Saipan Tribune detailing the incident, two unidentified military C-130s came directly at and passed unannounced within 300 feet of a Star Marianas twin-engine plane.

The Star Marianas pilot was flying about 1 mile offshore coming across the channel toward Tinian, south of the approach to runway 7's instrument landing system, or ILS, from Saipan.

The pilot was flying passengers and was 1,500 feet at standard altitude and routing flown by Star Marianas, according to the document. The plane was still within the Saipan tower's airspace, or Delta airspace.

"… I suddenly spotted one C-130 coming directly at me from the direction of Northfield at my altitude and definitely within Delta airspace," said the Star Marianas pilot, whose name was redacted from the report.

The C-130 was followed by another C-130, which was slightly off the lead C-130's left wing, the pilot said.

Both planes had nose-high altitude and were climbing in the pilot's direction, the pilot stated.

The C-130s came directly through the standard altitude and routing flown by commercial planes between the islands.

"I called tower and reported that a C-130 was coming at me and stated it passed within about 300 feet of my aircraft and asked if they knew about that aircraft being there. The tower stated that they had not known and that the aircraft had just called them," the pilot said.

The pilot noted that military aircraft often use ultra-high frequencies, or UHF frequencies, that civilian aircraft do not have. This makes civilian aircraft unable to hear communication from military aircraft when they use these frequencies.

The pilot said that if the Saipan tower's comments regarding the communication with the military aircraft was correct, both C-130s had violated the requirement to establish communication with the tower "prior to entering the Delta airspace, as my aircraft and theirs were clearly inside the Delta airspace when the incident occurred."

In an interview close to press time, Star Marianas president Shaun Christian confirmed the details the pilot had reported.

He said they look to the Federal Aviation Administration to see what the next course of action is, as they recently reported the incident to the FAA office in Guam, as a "near midair collision," or NMAC.

NMAC is defined as "an incident associated with the operation of an aircraft in which a possibility of collision occurs as a result of proximity of less than 500 feet to another aircraft," or a report that stated a collision hazard existed between two or more planes.

Christian said the plane so far had not been unidentified and that it is believed it came from the military branches involved in last month's Cope North exercise.

He said the plane was grey colored.

Christian called the incident a "communication problem," as it was unclear whether the military had duly informed the Saipan tower of its approach into civilian airspace.

"According to our pilot, no announcement had been made prior to entering Delta airspace," he said.

"There needs to be procedures and plans for better communication" between the military and the local airport, he said.

This air incident comes at a time when both Saipan and Tinian airport activity continues to increase, according to Star Marianas.

Saipan averages 298 flights per day, and Tinian averages 137 flights per day, for a combined 350 flights, according to Star Marianas. Some days there are more than 400 civilian commercial flights conducted within the 10 miles of airspace between the islands of Saipan and Tinian, Star Marianas claims.

"Adding military into that airspace, which is already nearly saturated at times, is creating unacceptable levels of risk, especially given the limited resources provided to the tower and ATC [air traffic control]."

Star Marianas noted that if flight operations continue to grow, ATC must be provided with radar to help ensure adequate separation of traffic, as is done in Guam.

The airline recommends that the military be held responsible for compliance with the rules and regulations required by the FAA.

They recommend that military flight operations should not interfere with civilian traffic operating between Saipan and Tinian, and that the military should refrain from climbing through the standard civilian flight path between islands.

Saipan Tribune contacted the Commonwealth Ports Authority to identify the C-130 planes, and verify if the military did not actually call the tower in due time, but no answer or additional details could be had before press time.

Saipan Tribune

Go back to Pacific Islands Report

EXHIBIT J

Boo... re... revised 9/..

NPS Form 10-900 (3-82)

NHL — WWII, PACIFIC

OMB No. 1024-0018 Exp. 10-31-84

United States Department of the Interior
National Park Service

For NPS use only

received

date entered

National Register of Historic Places Inventory—Nomination Form

See instructions in *How to Complete National Register Forms*
Type all entries—complete applicable sections

1. Name

historic: Tinian Landing Beaches, Ushi Point Field, and North Field, Tinian Island

and or common: North Field Historic District

2. Location

street & number: ___ not for publication

city, town: Tinian Island ___ vicinity of

state: Commonwealth of Northern Mariana Islands code 75 county Mariana Islands code 010

3. Classification

Category	Ownership	Status	Present Use	
X district	X public	___ occupied	___ agriculture	___ museum
___ building(s)	___ private	X unoccupied	___ commercial	___ park
___ structure	___ both	___ work in progress	___ educational	___ private residence
___ site	**Public Acquisition**	**Accessible**	___ entertainment	___ religious
___ object	___ in process	X yes: restricted	___ government	___ scientific
	___ being considered	___ yes: unrestricted	___ industrial	___ transportation
		___ no	X military	X other: none

4. Owner of Property

name: Government of the Commonwealth of Northern Mariana Islands

street & number:

city, town: Saipan ___ vicinity of Mariana Islands state

5. Location of Legal Description

courthouse, registry of deeds, etc.: Government of the Northern Mariana Islands

street & number: Lands and Survey Division

city, town: Saipan state: Mariana Islands

6. Representation in Existing Surveys

title: North Field Historic District has this property been determined eligible? X yes ___ no

date: August 23, 1982 X federal ___ state ___ county ___ local

depository for survey records: National Register of Historic Places

city, town: Washington state: D.C.

7. Description

Condition		Check one	Check one
___ excellent	___ deteriorated	___ unaltered	X original site
___ good	___ ruins	X altered	___ moved date
X fair	___ unexposed		

Describe the present and original (if known) physical appearance

The northern end of Tinian Island is relatively flat land having an elevation of about 75 feet above sea level. Before the 1944 battle this area, other than two airfields, was a checkerboard of sugar cane fields. Nearly all the coastline is sheer coral-limestone cliffs dropping into the ocean. On the northwest coast are three breaks in this cliff where small sandy beaches have formed. The most northerly of these, Unai Lamlam, has no historical significance. During the 1944 invasion of Tinian by U.S. Marines the two southern beaches were code-named Beaches White 1 and 2. They are about 1,000 yards apart. Beach White 1 (Unai Babui) is sixty yards wide. At either end of it are low coral ledges which are exceedingly sharp and uneven. Southwest is Beach White 2 (Unai Chulu) which is 120 yards in width. A small coral reef extends about 100 yards from the shore. At each end of the beach are coral ledges and perpendicular coral cliffs. Inland from Beach White 2 is a Japanese reinforced-concrete pillbox in fair condition. It is one of two that the Marines encountered when landing. Thick vegetation smothers the ground inland.[1]

The Japanese constructed an excellent military airfield toward the northern end of Tinian, Ushi Point (Puntan Tahgong). Nothing remains of the runway or taxiways at Ushi Point Field; but a concrete aircraft service apron and four structures remain from the Japanese period. These features are north of the western end of the northernmost B-29 runway. The concrete apron measures 750 by 300 feet. Weeds grow in cracks, but the apron is relatively intact. North of the apron is the large, two-story, T-shaped air administration building. It suffered some damage during the battle, particularly a large bomb hole in the roof. The building is of standard Japanese design and is similar to structures on Peleliu Island and at Truk Atoll.[2] In addition to administrative offices and a power plant, the building contained the quarters of senior air officers on the second floor. The finely decorated stairway to this floor remains as do bath and toilet facilities. To the rear of the structure are three, large concrete cisterns.

At the southeast corner of the apron, the concrete air operations building, minus its control tower, is in good condition. Even the exterior steel rungs for access to the roof are in place. It is identical to operations buildings on Saipan and Roi islands. The Americans used it as their operations center after

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1. By coincidence, the Japanese people on Tinian also called these popular swimming places the White Beaches before the war. Henry I. Shaw, Jr., Bernard C. Nalty, and Edwin T. Turnbladh, Central Pacific Drive, History of U.S. Marine Corps Operations In World War II, vol. 3 (Washington: U.S. Government Printing Office, 1966), p. 358.

2. The writer has not seen the structure at Truk. The information is from D. Colt Denfeld, "Survey of Peleliu," draft, Historic Preservation Office, Trust Territory of the Pacific Islands, Saipan.

8. Significance

Period	Areas of Significance—Check and justify below			
__ prehistoric	__ archeology-prehistoric	__ community planning	__ landscape architecture	__ religion
__ 1400–1499	__ archeology-historic	__ conservation	__ law	__ science
__ 1500–1599	__ agriculture	__ economics	__ literature	__ sculpture
__ 1600–1699	__ architecture	__ education	X military	__ social/ humanitarian
__ 1700–1799	__ art	__ engineering	__ music	__ theater
__ 1800–1899	__ commerce	__ exploration/settlement	__ philosophy	__ transportation
X 1900–	__ communications	__ industry	__ politics/government	__ other (specify)
		__ invention		

Specific dates 1944-1945 **Builder/Architect**

Statement of Significance (in one paragraph)

The capture of Tinian in the summer of 1944 by U.S. Marines was significant for several reasons. By selecting almost impossibly small landing beaches, the Marines confused Japanese commanders and established a beachhead at little cost in lives. Despite the narrow beaches (a total of 180 yards in width), two Marine divisions succeeded brilliantly in a difficult amphibious operation. Lt. Gen. Holland M. Smith, USMC, called this "the perfect amphibious operation in the Pacific war."[1] In the first night of the battle, the Japanese employed their usual tactic of attempting to destroy the enemy on the beach. It was a fatal effort for it cost them up to 2,000 lives, including some of their best infantry troops. Future battles would see Japanese defenses arranged in depth, inflicting heavier casualties on the enemy.

Tinian's topography provided the U.S. Army Air Force with a superb platform for constructing two long-range B-29 bomber airfields, including North Field, the largest airfield in the Pacific and perhaps in the world during World War II. From Tinian's six runways, as well as from bases on Saipan and Guam, armadas of B-29s raided and destroyed Japanese cities and towns in the homeland, shipping in Japan's coastal waters, petroleum supplies, and industrial plants. Finally, B-29s Enola Gay and Boch's Car flew from Tinian's North Field to drop atomic bombs on Hiroshima and Nagasaki, thus bringing a conclusion to World War II and changing forever the course of world events.

Japanese Tinian

During the Spanish regime, Tinian Island was virtually depopulated through disease, rebellion, and forced removal of the Chamorros. After Germany purchased most of Micronesia from Spain in 1899, the island continued to be uninhabited. Japan's seizure of Micronesia in World War I brought a great change to Tinian as Japanese citizens arrived to develop a sugar industry. By World War II, Tinian had a civilian population of 15,000 Japanese and Koreans. Fifty-eight percent of the island's thirty-nine square miles was planted with sugar cane. Two sugar cane mills were in operation and an extensive system of narrow-gauge railroad covered the island. Early in 1944, as Allied pressure grew in the Pacific, the Japanese removed from 3,000 to 5,000 civilians to

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1. Holland M. Smith and Percy Finch. Coral and Brass (Washington: Zenger, 1948, reprint 1979), p. 201.

9. Major Bibliographical References

See continuation sheet.

10. Geographical Data

Acreage of nominated property 2,610 (approx.)

Quadrangle name Tinian

Quadrangle scale 1:25,000

UTM References

	Zone	Easting	Northing
A	5 5	3 5 2 6 7 0	1 6 6 8 4 8 0
B	5 5	3 5 5 2 2 0	1 6 6 7 9 2 0
C	5 5	3 5 5 0 8 0	1 6 6 5 2 8 0
D	5 5	3 5 3 4 8 0	1 6 6 4 4 6 0
E	5 5	3 5 0 0 6 0	1 6 6 5 9 6 0
F			
G			
H			

Verbal boundary description and justification

See continuation sheet.

List all states and counties for properties overlapping state or county boundaries

state code county code

state code county code

11. Form Prepared By

name/title Erwin N. Thompson, Historian

organization National Park Service, Denver Service Center

date June 12, 1984

street & number 755 Parfet Street

telephone (303) 234-4509

city or town Denver

state Colorado 80225

12. State Historic Preservation Officer Certification

The evaluated significance of this property within the state is:

___ national ___ state ___ local

As the designated State Historic Preservation Officer for the National Historic Preservation Act of 1966 (Public Law 89–665), I hereby nominate this property for inclusion in the National Register and certify that it has been evaluated according to the criteria and procedures set forth by the National Park Service.

State Historic Preservation Officer signature

title date

For NPS use only

I hereby certify that this property is included in the National Register

date

Keeper of the National Register

Attest: date

Chief of Registration

the capture of Tinian. Stretching along the west side of the apron are two standard-design air raid shelters, also in good condition. These features of the Japanese field are surrounded by a forest of tangantangan, isolating them from the later American field. (Another Japanese runway a short distance to the south was destroyed during construction of American North Field.)

Once the capture of Tinian was completed, U.S. Navy Seabees began the construction of North Field in this area. When completed, North Field was the largest airfield in the Pacific, perhaps in the world. Designed for a wing of B-29 bombers (Superforts), the four parallel runways stretch east and west for 8,500 feet. Around and between the runways are nearly eleven miles of taxiways. Hardstands were constructed for 265 bombers. Two large asphalt service aprons exist. The asphalt runways are in relatively good condition, the northernmost (Runway 1 or A) apparently being maintained for periodic training exercises that are conducted on northern Tinian by the U.S. Department of Defense. No American quonsets or other buildings remain in the area.

North of the northern runway and the Japanese structures is a special, asphalted service apron. Here, the two B-29 bombers, Enola Gay and Boch's Car, were loaded with the first atomic bombs to be used in warfare. Because the bombs were too large to be placed under the planes for loading, a special pit was built for each weapon. Once the bombs were in the pits, the bombers simply moved over them and the bombs were raised into the bays. Both pits have been filled with earth and landscaped. In front of each is a bronze historical plaque mounted on a concrete pedestal. The setting is simple, but awesome.

After the battle, Seabees developed a large port at Tinian Town (San Jose) in southwest Tinian Island. To speed the delivery of supplies and munitions to the airfields, the Seabees built two north-south highways, Eighth Avenue (2 lanes) and Broadway (4 lanes).[3] At their northern terminuses, both roads ended in traffic circles. Both circles exist and the one at the end of Broadway contains a prewar Japanese memorial.

The historically significant area of northern Tinian contains the following historic features:

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3. Because Tinian is shaped much like Manhattan, the Americans named their roads after New York City's streets: Riverside Drive, 72d Street, Wall Street, etc.

Landing Beaches White 1 and 2
Japanese pillbox at Beach White 2
Japanese service apron, air administration building, air operations building, and two air raid shelters of former Ushi Point Field
North Field: four B-29 runways, taxiways, and two service aprons.

West of the field is a small lake or pond. While it in itself is not historic, one of the two major Japanese counterattacks of the battle, attacks that cost the Japanese dearly, was mounted in its vicinity. Thus, this general area is also considered significant. Northern Tinian also contains the sites of former American antiaircraft batteries and four administrative areas for American aircraft service groups on the west, north, and east sides. There are no known above-ground features at these sites. No known non-historic structures are within the recommended boundaries.

Northern Tinian is public domain owned by the Commonwealth of the Northern Mariana Islands. It is leased to the U.S. Department of Defense and is administered by the U.S. Navy.

Tinian Place Names

1944	Traditional Chamorro Place Names
Asiga Bay	Unai Asiga
Beach White 1	Unai Babui
Beach White 2	Unai Chulu
Fabius San Hilo Pt.	Puntan Lananibot Sankilo
Gurgan Pt.	Puntan Diapblo
Lalo Pt.	Puntan Carolinas
Marpo Pt.	Puntan Kastiyu
Masalog Pt.	Puntan Masalok
Mt. Lasso	Lasu
Mt. Maga	Maga
Southern ridge	Carolinas and Kastiyu
Sunharon Harbor	Tinian Harbor
Tinian Town	San Jose
Ushi Pt.	Puntan Tahgong

Japan.[2] The rest, however, were caught up in the American invasion in July 1944.

By the summer of 1944, Tinian's naval and army garrisons amounted to 8,350 personnel. The principal defense unit was the 4,000-man 50th Infantry Regiment commanded by Col. Keishi Ogata. Naval air personnel amounted to 2,100. The 56th Naval Guard Force of 1,100 men manned coastal defense and antiaircraft guns. Another 1,000 men composed the 233d Construction Battalion. Captain Goichi Oya commanded the naval forces, even though Vice Adm. Kakuji Kakuda, commander of the First Air Fleet, was the senior naval officer on the island.[3] As in other Pacific areas, there was little cooperation between the army and navy commanders.

Colonel Ogata surmised that the Americans would attempt a landing either at the beaches at Tinian Town on the southwest coast or at Asiga Bay on the island's east coast. He established strong defenses at both. He did not entirely neglect the White Beaches in the northwest. The larger beach was mined and pillboxes could deliver a crossfire on the beach. The smaller White Beach had few defenses. Who would attempt a landing on a 60-yard-wide stretch of sand?

American Plans and People

The U.S. Marines' assault on Tinian was considered to be Phase III of Operation FORAGER which began with the capture of Saipan (Phase I) and the battle for the liberation of Guam (Phase II) which was raging even as the Marines approached Tinian. Under the overall command of Adm. Chester W. Nimitz at Pearl Harbor, Adm. Raymond A. Spruance led the Fifth Fleet toward the Marianas. Vice Adm. Richmond K. Turner, as commander of the Joint Expeditionary Force, was responsible for both the Northern Attack Force (Task Force 52, Saipan and Tinian) and the Southern Attack Force (Task Force 53, Guam). He had relinquished direct control of the Northern Attack Force by the time of the Tinian invasion to Rear Adm. Harry W. Hill. Lt. Gen. Holland M. Smith, USMC (still in command of Expeditionary Troops), was off Guam with Admiral Turner. Maj. Gen. Harry Schmidt, USMC, had recently taken over the Fifth Amphibious Corps which consisted of his old command, the battle-hardened

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2. The nearly 1,000 Chamorros on Tinian today moved there from Yap Island after World War II. They had migrated to Yap from Guam in the late 1800s where both Germans and Japanese employed them as copra traders and workers.

3. Admiral Kakuda led the air attack on Dutch Harbor and Fort Mears in the Aleutians in 1942. Apparently, he had a problem with alcohol by 1944. See Frank O. Hough, The Island War, The United States Marine Corps in the Pacific (Philadelphia: J.B. Lippincott, 1947), pp. 254-255.

Fourth Marine Division, now under Maj. Gen. Clifton B. Gates, and the experienced Second Marine Division, still commanded by Maj. Gen. Thomas E. Watson. Both divisions had fought throughout the Saipan campaign and had continued to mop up that island until their departure for Tinian. The invasion of Tinian, J-Day, was set for July 24, 1944.

Bombardment

The first fast carrier strike on the Marianas occurred on February 23, 1944, when the planes of six carriers under Rear Adm. Marc A. Mitscher bombed Saipan, Tinian, Rota, and Guam. From June 11 to 15, 1944, Mitscher returned to the attack with four fast carrier groups (15 carriers) accompanied by battleships, cruisers, and destroyers. This attack reduced Japanese air strength in the Marianas to near zero. By mid-July no fewer than fifteen battalions of field artillery under Brig. Gen. Arthur M. Harper, USA, on southern Saipan were sending thunder toward northern Tinian. Naval ships began bombarding Tinian as early as June 13. As the invasion date neared the Navy's fire intensified, virtually demolishing Tinian Town. The Army's P-47 fighters and B-24 bombers on Saipan joined the attack even before that island was subdued. These planes were the first in the war to experiment in combat with the new napalm fire bomb, burning out cane fields and underbrush on Tinian. On J-minus-one, July 23, army and carrier planes, field artillery, and naval gunfire blasted Tinian.

Invasion

At daybreak, July 24, elements of the Second Marine Division, supported by aircraft and warships, carried out a deception off Tinian Town. Battleship Colorado supported the ruse with neutralizing fire. Suddenly, a concealed Japanese battery of three 6-inch guns opened fire and scored 22 direct hits on Colorado and destroyer Norman Scott. A total of 53 sailors and Marines were killed and 207 wounded.[4] Meanwhile, the Fourth Marine Division made the real landing at Beaches White.

At 7:47 a.m., July 24, the first Marines of the 24th Regiment touched shore at Beach White 1. The regiment landed in a column of battalions with the 2d Battalion leading. A small force of Japanese opened fire and mortar and artillery fell on the beach area. The Marines pushed ahead and within an hour two battalions were abreast and moving rapidly. The 24th Regiment's right reached its first objective, the edge of the runway south of Ushi Point Field,

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4. Colorado had been in drydock at Puget Sound when the Japanese struck at Pearl Harbor. She survived this attack and was in Tokyo Bay for Japan's surrender. Mothballed in 1947, the ship was scrapped in 1959.

1,400 yards inland, by 4:00 p.m. A stubborn group of Japanese halted the regiment's left flank 400 yards short of its objective.

Beach White 2 was more difficult. Because of mines in the sand, the first units of the 25th Regiment had to jump or climb from the craft to the ragged coral ledges at the ends of the beach. Japanese defenses were more extensive in this area, yet the Marines forged ahead, bypassing two pillboxes that commanded the beach. The 25th Marines halted short of their first objective in late afternoon and dug in for the anticipated Japanese counterattack. Division commander Cates ordered the 23d Marines ashore as a reserve. Also on shore was a battalion of the 8th Marines, Second Division, making a total of 15,600 combat Marines who had landed on two handfulls of sand in less than twelve hours.

Counterattack

The Fourth Marine Division dug in along a 3,000-yard-wide beachhead, 24th Marines on the left (north), 25th Marines in the center, and 23d Marines on the right (south). Beginning at 2:00 a.m., July 25, Colonel Ogata's forces began a counterattack to drive the enemy into the sea. In the north some 600 naval troops from Ushi Point Field engaged in a firefight with the 24th Marines, striking hardest at the extreme left near the coastline. For three hours the Japanese attempted unsuccessfully to break through the invaders' lines. At dawn, the 24th Marines counted 476 enemy dead.

Ogata's crack infantry troops assaulted the center of Marine lines near the boundary of the 24th and 25th regiments. The first attack was thrown back, but the Japanese regrouped and pressed forward again. About 200 of them broke through the lines. Half of them headed toward the Marines' artillery positions near the beach. The artillerymen opened up their machine guns and, aided by a company from the 8th Marines, wiped out the attackers. The other group of Japanese infantrymen got behind the 25th Marines' positions where machine gun and mortar fire quickly eliminated them. This attack on the center cost the Japanese 500 lives.

The 23d Marines on the south faced an attack from a combined infantry-tank force. Five light tanks, nearly half of Ogata's armor strength, rumbled up the coastal road. All five were destroyed by Marine fire but not before three of them broke through the 23d's front. Japanese infantry continued to fight desperately but, by dawn, the attack exhausted itself. Marines counted 267 enemy dead. All told, the Japanese lost 15 percent of their personnel strength and 50 percent of their armor in this costly attempt to defeat the enemy on the beaches.[5] Although more fighting lay ahead, General Gates concluded that his division had broken the enemy's back on its first night ashore on Tinian.[6]

Tinian Won

The Second Marine Division completed landing on Beaches White 1 and 2 on July 25 and 26, its 8th Marines taking over the extreme left (north) of the front. By the evening of the 25th, the Marines had advanced to Ushi Point Field in the north and had taken Mt. Maga in the south.

The Second Division swept to Tinian's east coast on July 26, then turned south. On the west, the Fourth Division captured Mt. Lasso, Tinian's highest point. Seabees began repairing the airfield for fighters.

Resistance remained light as the Marines advanced southward, indicating that the Japanese were withdrawing. On July 30, the 24th Marines entered the wrecked and deserted Tinian Town. Beyond the town, an oblong-shaped plateau, over 500 feet in elevation, formed the southern and southeastern end of Tinian. In the center a twisting road led to the top of the tree-covered plateau. A vertical cliff dropped into the sea on the eastern side. The slopes were more gentle at the southwest end of the plateau where they formed three distinct terraces. The Japanese prepared to make this high ground their last stand.

In the morning of July 31, an American naval and aerial bombardment blasted the plateau with 684 tons of explosives. A naval gunfire officer wrote, "Observers report that this was probably the most intense and effectively controlled bombardment executed thus far in the Pacific."[7] Following the bombardment, the Second Division moved forward on the left toward the base of the cliff, encountering sniper fire as it advanced. Large numbers of civilians began surrendering, interferring with the Marines' progress. In the afternoon elements of the 8th Marines reached the top of the plateau via the heavily defended road. During the night the Japanese attempted, in vain, to cut the

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5. The official Marine Corps history states that 1,241 Japanese died in the counterattack. General H.M. Smith thought the number was closer to 2,000. Other accounts offer different figures.

6. G-3, Fourth Marine Division, Operations Report, Tinian, U.S. Marine Corps, World War II Records, Washington National Records Center, Suitland, MD, hereinafter cited as WNRC.

7. Lt. C.S. Corben to Commanding General, Northern Troops and Landing Force, August 12, 1944, U.S. Marine Corps Records, World War II, WNRC.

road; and before dawn, August 1, 750 of them made a banzai attack on the Marines on the plateau. An hour-long firefight resulted in 74 casualties in the 8th Marines and 200 Japanese dead.

During July 31, the Fourth Division also succeeded in placing Marines on the plateau. Meanwhile, a wide gap had developed between the two divisions, a gap the Japanese were not able to exploit. The division expanded its hold on the plateau on the following day and reconnoitered the terraces on the ocean side. Progress was again slowed by crowds of Japanese and Korean civilians emerging from caves to surrender. Some, however, preferred suicide. That evening, General Schmidt announced that Tinian had been secured.

Fighting continued. The Japanese made several more banzai attacks for several days as Marines went about the dangerous task of mopping up Tinian. In a final accounting, the two divisions' casualties amounted to 355 killed, 1,550 wounded, and 27 missing in action. More than 5,500 Japanese troops lost their lives, while 404 were taken prisoner. More than 13,000 civilians, mostly Japanese, were interned on Tinian until the end of the war.

North Field

While fighting on Tinian continued, the Navy's Seabees began the repair and extension of the two Japanese runways in the north. Because of the relative flatness of the terrain, Tinian had already been selected as the site for an advanced air base to serve very-long-range B-29 bombers which required 8,500-foot-long runways. The north end of the island had a capacity for four of these runways as well as an extensive network of taxiways, service aprons, and hardstands (aircraft parking). Eventually, the 6th Naval Construction Brigade was formed on Tinian, and work proceeded at a feverish pace.

The Japanese runway at Ushi Point Field became the basis for runway 1, the most northerly of the four, which was completed and asphalted January 1. 1945.[8] The Japanese runway south of Ushi Field was extended to become runway 3 and was completed two weeks later. Strip 2, between runways 1 and 3, was in operation on February 27; but runway 4 was not completed until May 5, 1945.

While North Field was under construction, the XXI Bomber Command's first B-29 raid on Japan flew from Saipan on October 24, beginning three months of

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8. The first B-29 landed on this runway on December 22, 1944.

daylight, high-altitude, precision attacks from the Marianas.[9] At the end of December 1944, the B-29s of the 313th Bombardment Wing (VH) began arriving at North Field (12,000 personnel, 180 aircraft). One month later, 122 of the big bombers had arrived. Meanwhile, the daylight precision raids on Japanese aircraft industries were proving disappointing. Relatively little damage was inflicted on the plants, and losses of the big, expensive planes were greater than expected. Maj. Gen. Curtis E. LeMay, who took command of XXI Bomber Command on January 20, decided to conduct a nighttime incendiary raid to test its effectiveness. On February 25, 231 Superforts lifted off at Saipan, Tinian, and the new North Field on Guam en route to Tokyo. The test proved most effective and almost 30,000 of Tokyo's buildings were destroyed. In March, the XXI Bomber Command began a series of incendiary attacks on a number of Japanese cities. Tinian's B-29s participated in all of them. The most terrible of these was an attack on Tokyo that burned 15.8 square miles of the city, killing almost 84,000 people and injuring 44,000 more in "perhaps the most scathing air attack of the whole war."[10] By mid-June, Japan's six most important industrial cities lay in ruins. In seventeen major incendiary attacks, 6,960 B-29s dropped 41,592 tons of bombs with few losses to themselves.

The 313th Wing at North Field received a special assignment in March 1945--aerial mining of Japanese waters. The bombers made their first attack between March 27 and April 1. Over 100 Superforts laid 1,500 mines in Shimonosaki Strait between Kyushu and Honshu islands. Japanese antiaircraft fire destroyed three of the planes. By the end of April, 18 Japanese ships had been sunk and shipping in general was disrupted. Mines forced the great battleship Yamato, heading a task force during the battle for Okinawa, to put to sea via Bungo Strait, thus leading to her destruction. In May alone, mines sank 85 ships. U.S. submarines, aircraft, and the 313th Wing's mines combined to force Japan to close most of its ports to shipping by the end of July. Japan lost 478,000 tons of shipping in that month. In addition, the 313th Wing dropped millions of leaflets urging the Japanese people to surrender before starving.

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9. The XX Bomber Command had already been established in India and, staging through China, was also bombing Japan. In 1945, both commands were disbanded and the XXI Bomber Command became the Twentieth Air Force, a component of U.S. Strategic Air Forces. Headquarters were on Guam, and five wings carried out raids from Guam, Tinian, and Saipan.

10. Wesley Frank Craven and James Lea Cate, eds., The Pacific: Matterhorn to Nagasaki, June 1944 to August 1945. The Army Air Forces In World War II, vol. 5 (Chicago: University of Chicago Press, 1953), pp. 614-617.

Atomic Bombs

On May 19, 1945, a new, secretive organization began arriving at North Field, the 1,767-man 509th Composite Group headed by Col. Paul W. Tibbets, Jr. Tight security was provided the group which occupied a former Seabee camp--to the discomfort of the navy men. Likewise, the group's stripped-down B-29s were closely guarded. Because the 509th Group did not take part in the raids on Japan, airmen of the 313th Wing ridiculed the newcomers, even to the extent of stoning the encampment. Meanwhile, the 509th pilots practiced special flying techniques (only Tibbets knew why), mostly over Japanese-held Rota Island and Truk Atoll. Beginning July 20, the group began flying over Japan to familiarize itself with targets and tactics. About that time, cruiser Indianapolis arrived at Tinian bearing uranium 235.[11]

At 2:45 a.m., August 6, Enola Gay[12] left runway 1 at North Field on its historic mission. At 8:15 a.m. the plane dropped an atomic bomb on Hiroshima. Seconds later, 80,000 people were dead or mortally wounded; 62,000 buildings were destroyed. Enola Gay returned to Tinian at 2:58 p.m. The world would never be the same.

On August 9, Maj. Charles W. Sweeney, in Bock's Car, dropped a second bomb on Nagasaki, nasty weather having prevented his attacking the primary target, Kokura. Low on fuel, Sweeney was forced to land at the new American base on Okinawa. Before he was able to return to North Field, Tinian, President Harry S Truman announced Japan's unconditional surrender.

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11. A Japanese submarine sank Indianapolis a few days later, with a fearsome loss of life.

12. Tibbets flew in the B-29 assigned to Capt. Robert Lewis who was present as copilot. Before takeoff, Tibbets had his mother's name, Enola Gay, painted on the aircraft, much to Lewis' annoyance.

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Corben, USNR, Naval Gunfire Officer, to Commanding General Northern Troops and Landing Forces, hereinafter NTLF, Naval Gunfire Report, Tinian, August 12, 1944; NTLF: Annex BAKER to Operations Plan 30-44, Phase III (Tinian), July 13, 1944; Operations Report, Marianas, Phase II (Tinian), with Annexes, August 12, 1944; Daily Dispatch Summaries, July 10-August 10, 1944; Journal, Tinian, July 23-August 8, 1944; and G-3, Periodic Report, July 23-August 10, 1944, all in U.S. Marine Corps World War II Records, Washington National Records Center, Suitland, MD.

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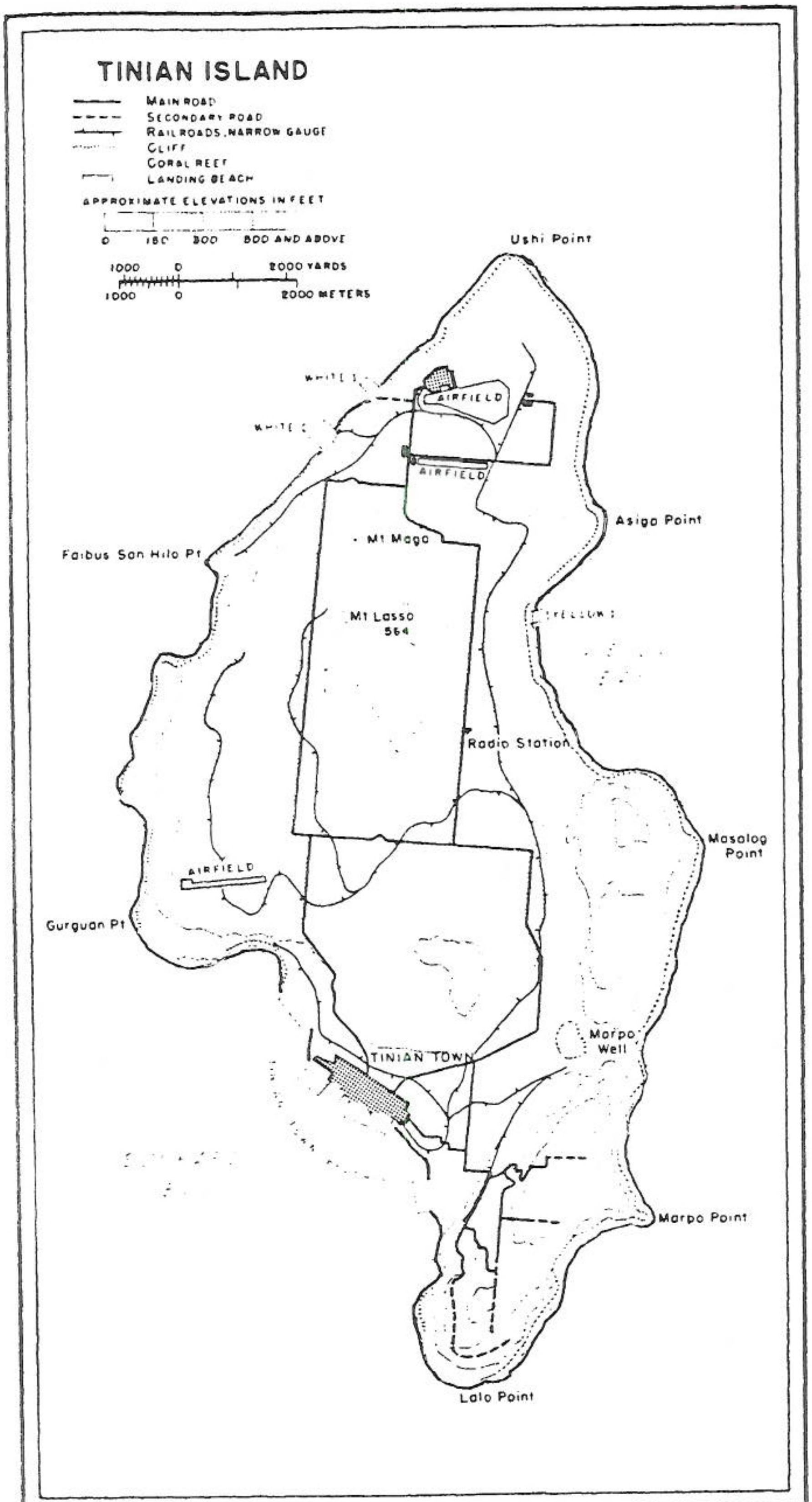
GEOGRAPHICAL DATA

Starting at a point on the northwest coast of Tinian 800 feet northeast of Unai Lamlam, then following the coast in a southwesterly direction to a point 1,600 feet southwest of the south end of the reef at Unai Chulu. Then east, southeast in a straight line to the westernmost point of the traffic circle at the head of 8th Avenue. Then following the exterior (northern) perimeter of the traffic circle to its east side where it joins a narrow road. Then east along the northern boundary of the road to a junction marked BM 10.6. Then south and southeasterly along the inner boundary (eastern and northern) of a narrow road to the traffic circle at the north end of Broadway. Then along the outside (northern) perimeter of the traffic circle to its junction with a narrow road running north, then following along the inner (western) boundary of the road as it curves to the east, northeast, and continuing along the inner (northern) boundary of the narrow road to a point where it curves to the north. Then with the inner (western) boundary of the narrow road north 6,800 feet, then southwest with the inner boundary of the narrow road 1000 feet, then northwest with the inner boundary of the narrow road 2000 feet, then northwest with the inner boundary of the road 2000 feet, and then west, northwest 3,600 feet to the point of beginning.

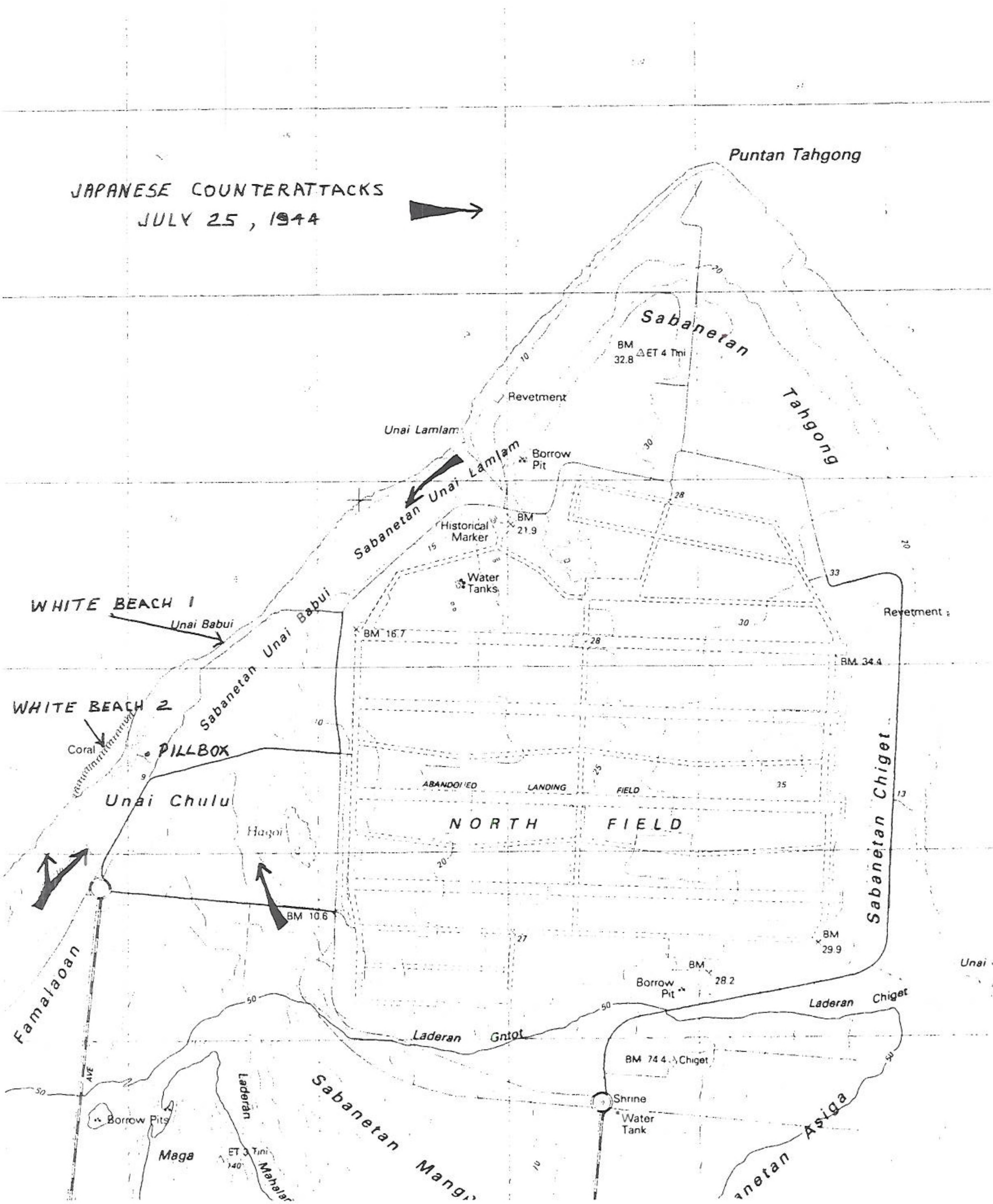
These boundaries include all the significant historical features in the nomination: Landing Beaches White 1 and 2; U.S. Marines' beachhead; Japanese counterattacks of July 25, 1944; Japanese structures at Ushi Point Field; and North Field.



D. Holmes, Jr.

Printed by the U. S. Army Topographic Command

FROM PHILIP A. CROWL, <u>CAMPAIGN IN THE MARIANAS</u>



JAPANESE COUNTERATTACKS
JULY 25, 1944
Puntan Tahgong
Sabanetan Tahgong
BM 32.8 ET 4 Tini
Revetment
Unai Lamlam
Sabanetan Unai Lamlam
Borrow Pit
Historical Marker
BM 21.9
Water Tanks
WHITE BEACH 1
Unai Babui
Sabanetan Unai Babui
BM 16.7
Revetment
BM 34.4
WHITE BEACH 2
Coral
PILLBOX
Unai Chulu
Hagoi
ABANDONED LANDING FIELD
NORTH FIELD
Sabanetan Chiget
BM 10.6
BM 29.9
BM 28.2
Borrow Pit
Unai
Laderan Chiget
Famalaoan
Laderan Gntot
BM 74.4 Chiget
Shrine
Water Tank
Borrow Pits
Laderan
Maga
ET 3 Tini
Sabanetan Mang
Sabanetan Asiga

NORTH FIELD, TINIAN
1944 - 1945

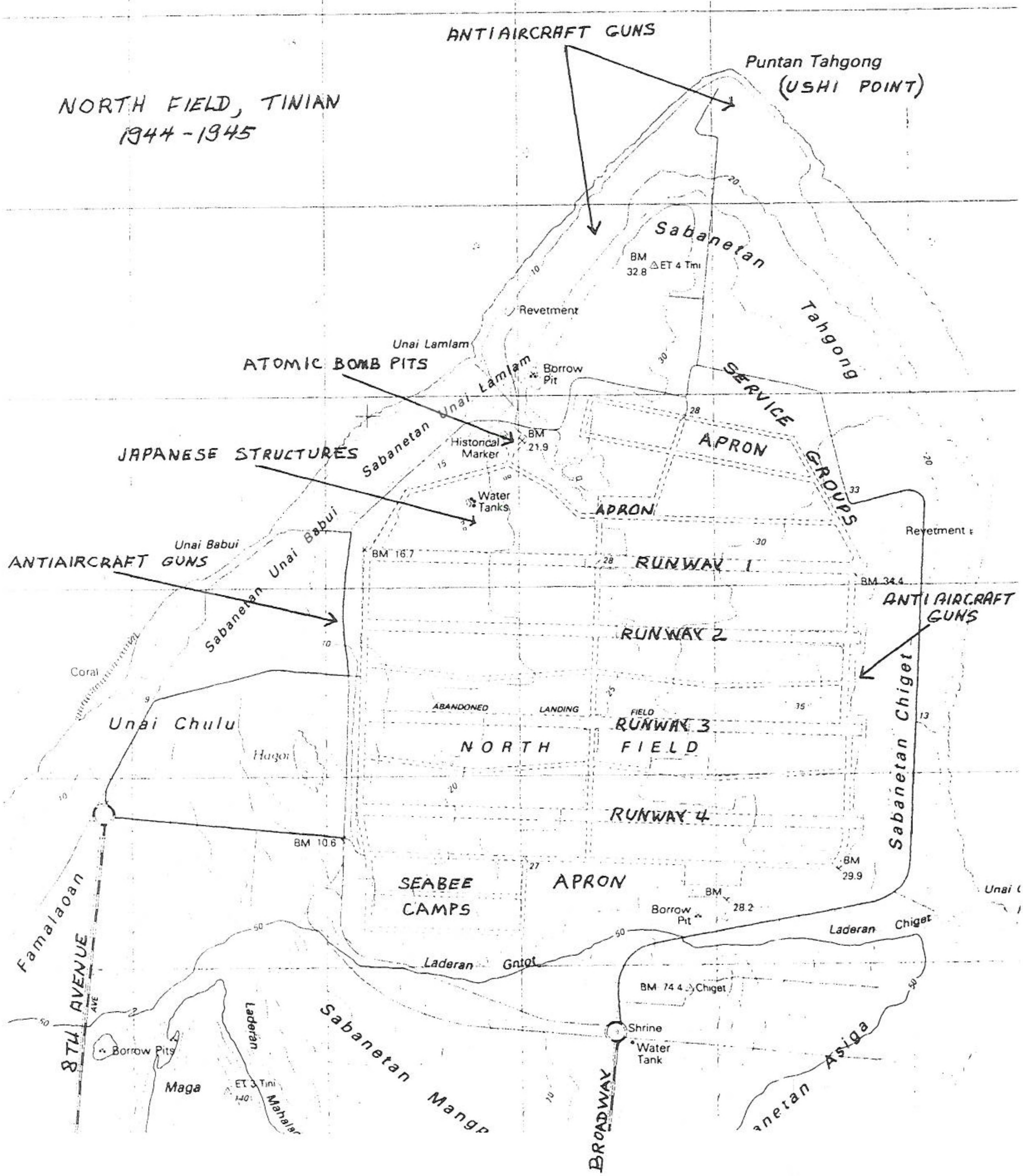


EXHIBIT K

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION IX
75 Hawthorne Street
San Francisco, CA 94105

June 18, 2015

Nora Macariola-See
Naval Facilities Engineering Command, Pacific
258 Makalapa Drive, Suite 100
Pearl Harbor, Hawaii 96869-3134

Subject: Final Environmental Impact Statement for the Mariana Islands Training and Testing (MITT), Commonwealth of the Northern Mariana Islands (CNMI) (CEQ # 20150136)

Dear Ms. Macariola-See:

The U.S. Environmental Protection Agency (EPA) has reviewed the above-referenced document pursuant to the National Environmental Policy Act (NEPA), Council on Environmental Quality (CEQ) regulations (40 CFR Parts 1500-1508), and our NEPA review authority under Section 309 of the Clean Air Act.

EPA reviewed the Draft Environmental Impact Statement (DEIS) and provided comments to the Department of Defense (DoD) on December 12, 2013. We rated the DEIS as Environmental Concerns - Insufficient Information (EC-2), primarily due to concerns regarding erosion from increased bombing of Farallon De Medinilla (FDM) and the impacts that the resulting increased sedimentation could have on corals that surround the island.

We appreciate the figure added to the FEIS that shows the distribution and percent cover of corals surrounding FDM, as we recommended. The FEIS also includes results from dive surveys the Navy conducted since 1999 (p. 3.1-26). According to the FEIS, impacts to the physical environment clearly attributable to military training activities were noted in 2007, 2008, 2010, and 2012 (p. 3.1-27), but the FEIS states that the coral fauna at FDM during these surveys was observed to be healthy and robust (p. 3.3-33). This statement appears to be contradicted in the 2012 dive report[1], which documents a severe coral barnacle infestation and identifies it as a "significant adverse change". The dive report concludes that this is not a result of military training; however, this conclusion is based solely on the fact that these barnacles were also found on a reef north of FDM. The dive report suggests, as a possible explanation, that the presence of high densities of barnacles indicates the corals are "*highly impacted by other stressors*", noting that, "*Coral barnacles can be likened to an "opportunistic infection" that are merely indicative of a "weakened immune system"*. It further states, "*It's these unknown stressors that are causing the Pocillopora to die*" (dive report p. 24). The presence of these barnacles on a reef north of FDM does not preclude the possibility that increased sedimentation and/or the presence of munitions constituents are contributing to the weakened immune system of the corals at FDM.

[1] NAVFAC, April 2013. *Calendar Year 2012 Assessment Of Near Shore Marine Resources At Farallon De Medinilla, Commonwealth of the Northern Mariana Islands*, Available: http://mitt-eis.com/DocumentsandReferences/EISDocuments/SupportingTechnicalDocuments.aspx

In addition, observations of existing coral health do not demonstrate that a training increase of the magnitude proposed would have a less than significant effect on corals surrounding FDM. The Proposed Action would include a substantial increase in the use of explosive munitions on FDM. The number of bombs dropped on land targets annually at FDM would increase three-fold (from 2,150 to 6,242). DoD also proposes to increase explosive missile use annually by 42% (from 60 to 85), introduce 2,000 explosive rockets not currently used, increase explosive grenades and mortars by 500% (from 100 to 600), and increase small-caliber rounds by 1,348% (from 2,900 to 42,000) (p. 3.0-42). These actions have the potential to greatly increase erosion and sedimentation. We recommend that the Record of Decision commit to annual dive surveys to continue to monitor the marine resources and the coral barnacle infestation at FDM, and that results from these surveys be made available to government agencies and the public.

In our comments on the DEIS, we noted that the range condition assessment did not assess the fate and transport of sediment, including munitions constituents, from FDM. We recommended that the FEIS discuss the results of the 5 year reassessment, if available. The FEIS does not indicate whether an update to the range condition assessment occurred. The previous assessment, dated May 2008, estimated source loading of residual munitions constituents at the range, but concluded that no further analysis was warranted since its uninhabited location poses no risk to human receptors[2]. As we commented on the Mariana Islands Range Complex DEIS[3], ecological receptors, in addition to human receptors, should be considered in the range condition assessments. Additionally, there is a potential for human receptors via a fish consumption pathway, which is not recognized in the range condition assessment conclusion. The FEIS notes that the waters surrounding FDM have been and continue to be an important area for local fishers (p. 3.12-22). The 2012 dive report (p. 41) identified evidence of increased fishing pressure at FDM and discussed possible causes, including increased enforcement of fishing restrictions around Saipan and Tinian and a general economic downturn in CNMI since 2010. In addition, while the 2008 range condition assessment had already acknowledged aerial bombing and ship bombardment training activities at FDM as "a significant source of munitions constituents" (p. ES-14), the Proposed Action would introduce 2,000 rockets per year at FDM not previously used there. According to the FEIS, rockets have a failure rate of almost 4% (Table 3.1-4), which leaves unconsumed explosives in the environment (p. 3.1-20). We recommend that future range condition assessments evaluate the fish consumption pathway, including potential sampling of fished species for munitions constituents, and that a commitment to this evaluation be included in the Record of Decision.

EPA appreciates the opportunity to review this FEIS. When the Record of Decision is signed, please send a copy to the address above (mail code: ENF-4-2). If you have any questions, please contact me at (415) 972-3521, or contact Karen Vitulano, the lead reviewer for this document, at 415-947-4178 or vitulano.karen@epa.gov.

Sincerely,

Kathleen Martyn Goforth, Manager
Environmental Review Section

[2] NAVFAC, May 2008. *Final Range Condition Assessment Marianas Land-Based Operational Range Complex Decision Point 1 Recommendations Report Guam and Commonwealth Northern Mariana Islands*, May 2008. Executive Summary available: http://www.denix.osd.mil/sri/upload/Final-Marianas-DP1-ES-Official.pdf

[3] EPA comment letter on the Mariana Island Range Complex (MIRC) DEIS, March 26, 2009

EXHIBIT L

Department of Defense
Legacy Resource Management Program

PROJECT NUMBER 05-238

BROWN TREESNAKE INTERDICTION AND PREVENTION OF SPREAD

DANIEL VICE
U.S. DEPARTMENT OF AGRICULTURE,
ANIMAL AND PLANT HEALTH INSPECTION SERVICE,
WILDLIFE SERVICES
Barrigada, Guam

SEPTEMBER 30, 2011

BROWN TREESNAKE CONTAINMENT PLAN FOR GUAM

Prepared by:
U. S. Department of Agriculture, Animal and Plant Health Inspection Service, Wildlife Services

September 2011

1.0 INTRODUCTION

The brown treesnake (*Boiga irregularis*, BTS) was accidentally introduced to the island of Guam shortly after World War II. The invasive snake colonized the island at densities reaching 80 individuals per hectare and is directly responsible for the extinction of 9 of 12 native forest birds historically found on Guam. The snake causes several hundred power outages annually, resulting in millions of dollars in damaged equipment, lost productivity, repair costs, and disruptions to the lives of island residents. Considered mildly venomous, BTS frequently enter homes, resulting in bites that send dozens of people (most often children or infants) to emergency rooms for treatment every year (*see* Rodda, G.H. and J.A. Savidge, 2007, Biology and impacts of Pacific Island Invasive Species, 2, Boiga irregularis, the Brown Tree Snake (Reptilia: Colubridae), Pacific Science 61(3):307-324.).

The BTS is a classic example of a generalist invasive species, occupying virtually all habitats on Guam. The BTS is arboreal and nocturnal in behavior. Primary prey items for BTS include birds, small mammals, and lizards; two super-abundant introduced lizards constitute the bulk of BTS food on Guam today. The cryptic nature of the BTS, coupled with its extreme abundance on Guam, create significant risk of dispersal from the island via civilian and Department of Defense (DoD) transportation networks. Snakes associated with Guam's transportation network have been found in Saipan, Tinian, Rota, Hawaii, and most other major islands in the tropical western Pacific, as well as the continental United States, Diego Garcia, and Spain. Given the role of Guam as the regional shipping hub within Micronesia, the snake presents a serious ecological and economic threat to Hawaii, the Commonwealth of the Northern Mariana Islands (CNMI), and virtually every other island group in the region, as well as subtropical regions of the U.S. mainland. The establishment of BTS in other locations would result in economic and ecological damage similar to that observed on Guam, potentially on a much larger scale (in the case of Hawaii). A recent University of Hawaii study has estimated the economic damages associated with the establishment of BTS in the state of Hawaii would cost between $29 million and $405 million annually.

The Federal Government has made considerable annual commitments to preventing the inadvertent spread of BTS via Guam's outbound cargo network. This document summarizes current BTS control methods and strategies, locations of strategic actions for BTS containment on Guam and provides recommendations for improvement of these efforts.

2.0 WILDLIFE SERVICES BTS CONTAINMENT EFFORTS

The United States Department of Agriculture, Animal and Plant Health Inspection Service, Wildlife Services (WS) is currently funded through Joint Region Marianas to prevent the inadvertent spread of BTS via the outbound DoD transportation network from Guam and from the U.S. Department of Interior, Office of Insular Affairs (DoI, OIA), to implement an analogous containment program in the island's commercial export industry. These activities are complimentary to each other, as many export activities are not mutually exclusive to a given port of exit (e.g., household goods movements that originate on DoD property are moved to commercial warehouses in the Harmon Industrial Park prior to their embarkation off island). Additional BTS containment efforts in the State of Hawaii and the Commonwealth of the Northern Mariana Islands (CNMI) are funded by DoI, OIA. These programs target inbound cargo, both military and civilian, that originate from Guam.

Containment is accomplished through an integration of wildlife damage management methods, incorporating a variety of population management techniques that target BTS populations in and around key cargo processing, staging, consolidation, and embarkation locations on DoD and civilian facilities. These facilities include Andersen Air Force Base, Naval Base Guam, the Guam International Airport, the Port Authority of Guam, and 30 private freight forwarding companies located throughout Guam.

2.1 Project Objective

To reduce the probability of BTS dispersal through the U. S. Department of Defense and civilian transportation networks on Guam.

2.2 Containment Strategies

1) Systematically reduce BTS populations around cargo facilities and port environments using snake traps, hand capture, oral toxicants, barriers, and prey base control;
2) Conduct canine inspections of outbound cargo resources for any BTS that may have circumvented primary population control measures;
3) Educate DoD and civilian personnel on the risks associated with BTS and how to respond to a BTS sighting in cargo;
4) Monitor the cargo network and amend control strategies, in coordination with DoD and civilian cooperators, to address changing processes and risks, and;
5) Provide guidance on cargo process changes, growth, and facility development to identify problematic BTS containment areas.

Wildlife Services concentrates containment efforts in cargo packing, handling, and staging "bottlenecks", where control activities offer maximum benefit. This targeted approach facilitates the most efficient delivery of resources, while minimizing the geographic scope of the project. Aircraft, ocean-going vessels, and the cargo and materials associated with air and surface transportation are all subjected to varying levels of containment. Priority efforts focus upon commodities that originate on Guam or have been staged on island prior to embarkation, as well as the facilities (i.e., warehouses) that support these activities.

2.3 Regulatory Compliance

Wildlife Services is a cooperative, cost-sharing federal agency, and all agency actions are in compliance with applicable local and federal laws, including the National Environmental Policy Act, the Endangered Species Act, and the Federal Insecticide, Fungicide, and Rodenticide Act. Wildlife Services activities are conducted in compliance with all pertinent installation policies. All budgetary implementation and execution is consistent with appropriate federal and agency regulations. All WS employees are full-time federal employees.

3.0 TOOLS AND TECHNIQUES FOR BTS CONTROL AND CONTAINMENT

Available methods for controlling BTS have been developed and evaluated over the past three decades through dedicated research and operational work. Current methods and strategies represent the best available technology and integration. Wildlife Services works closely with the USDA, National Wildlife Research Center and the U. S. Geologic Survey, to continually evaluate program results and integrate new technology and control strategies, as appropriate. The following sections describe specific operational tools available for BTS control and their implementation as they support BTS containment on Guam.

3.1 Snake Trapping

Brown treesnake traps are the primary control tool used to reduce BTS populations. The traps are modified minnow traps with self-setting flap doors, allowing multiple snake captures within one trap. Each trap contains a live mouse which serves as a lure. The mouse, its food, and water source are enclosed within a separate cage inside trap, which provides protection from snakes and other predators. Traps are situated to provide a secure perimeter, reducing the likelihood of a BTS entering cargo staging or processing facilities. Traps are placed along forest perimeters and security fence lines surrounding warehouses, wharves, and other critical cargo staging, processing, and/or embarkation points, typically at 20 meter intervals. Spacing may be increased in certain circumstances, as staffing resources and/or other logistic constraints dictate. Traps are serviced once weekly (also spot-checked during the week); at each check, any captured snakes are removed, and routine maintenance, including replacement of the food and water source for the mouse contained inside, is conducted. Fabrication of feed blocks, which are replaced weekly, is completed by WS employees and requires substantial staffing input. Wildlife Services fabricates BTS traps at a shop in Yakima, WA.

3.2 Nighttime Fence Line Searches

As BTS traps tend to capture primarily medium-sized BTS, hand capture of snakes is regularly implemented to expand the BTS population targeted by control efforts. Fence lines surrounding all cargo facilities and wharves on base are searched nightly by spotlight for BTS. Snakes that are encountered are removed by hand by WS personnel. When fully functioning, spotlighting activities account for nearly 25% of the total BTS take by WS. Canine handlers, working scheduled night shifts, conduct the majority of spotlighting activities.

3.3 Canine Detector Dog Teams

Prior to departing island, cargo, aircraft, and smaller ocean-going vessels are inspected with specially-trained BTS detector dog teams. Each team consists of a canine and their respective handler that have undergone extensive protocol and validation training. Canine teams conduct inspections for BTS that may have circumvented primary population control measures or stowed in cargo that originated outside snake-controlled areas. Wildlife Services currently employs 15 full time canine teams, based from kennels on Andersen Air Force Base and Naval Base Guam.

The timing of a given inspection is dependent upon the type of cargo or vessel; containerized commodities moving via surface (i.e., household goods, personally-owned vehicles (POV's), etc.) are, at a minimum, inspected during daylight hours on the day containerization is scheduled. Aircraft (including helicopters) are typically inspected within 3 hours of scheduled departure. General freight is inspected on a daily basis, regardless of the scheduled departure date.

Inspections of cargo that is to be containerized are conducted immediately prior to consolidation and containerization. Once a commodity has been placed inside a shipping container, inspection quality (and therefore snake detection probability) is greatly reduced.

3.4 Oral Toxicants

An oral toxicant, acetaminophen, is now registered by the U.S. Environmental Protection Agency for general field use in controlling BTS in Guam and the CNMI. The toxicant, an 80 mg tablet, is administered to BTS via a dead neonate mouse, placed inside a PVC delivery device or delivered aerially. Although operational efforts using toxicants have been relatively limited to date, WS is continuing to refine the application of toxicants and will be expanding their use in support of BTS control and interdiction as available technology improves.

3.5 BTS Barriers

Conceptually, BTS barriers are applied to protect a contained resource or to keep snakes from entering a defined area (an "exclusionary" barrier) or to keep snakes contained inside a defined area, such as a cargo processing point on a recipient island (a "containment" barrier). Barriers used for cargo protection on Guam would be exclusionary in design.

Barriers to block the movement of BTS are considered either permanent or temporary in design. Temporary barriers are constructed of shade cloth, supported by metal rebar inserted into the ground, with PVC pipe providing attachment points for the material to the rebar. Barriers may be utilized as exclosure barriers to prevent BTS from gaining access to a vulnerable area such as a cargo staging area or as enclosure barriers to prevent BTS (if present) from exiting a cargo staging area at a vulnerable site. Temporary barriers are typically employed by WS during large scale DoD exercises such as Tandem Thrust. Permanent barriers to block the movement of BTS have been rigorously tested and are now available for use in both cargo containment and conservation situations. However, their implementation on Guam has been limited by resource availability and institutional reluctance to install the structures.

3.6 Prey Base Control

An abundance of introduced rodents and/or birds in proximity to cargo processing facilities can increase the attractiveness of the area to BTS as well as reduce the efficacy of BTS detector dogs. To address this risk, control measures that reduce the availability of BTS prey are selectively implemented in and around cargo facilities. Anti-coagulant bait is the primary tool used for controlling rodents (including rats and mice) in and around cargo areas. Non-native Eurasian tree sparrows, pigeons, and black drongos in cargo facilities are controlled via shooting and live trapping. Effective management of cargo facilities, including appropriate waste disposal, removal of vegetation in proximity to buildings, and limiting the outdoor storage of materials and equipment, will reduce the attractiveness of a given area to rodents, lizards, and other potential BTS prey species.

3.7 Public Education and Outreach Programs

WS engages in public education and outreach programs primarily designed to target those involved with DoD and civilian transportation, as well as the general public and newly arriving military personnel. This outreach provides increased knowledge and understanding of Wildlife Services' mission, the BTS problem, and tools available to address BTS control and interdiction.

A variety of informational materials are available through WS, including two BTS awareness/training videos, brochures, fact sheets, and a "Pest Alert" poster. WS conducts regular briefings on BTS to newly arriving Navy members, DoD school groups, and employees of key cargo processing facilities. Nearly 50% of the BTS discovered directly in cargo over the past 10 years have been made by non-WS employees, supporting the importance of on-going awareness training for individuals working in the transportation network.

4.0 LOCATIONS OF PRIMARY CONTAINMENT ACTIVITIES

A combination of trapping, hand capture (spotlighting), toxicant application, and canine inspections for BTS are conducted in and around all cargo staging, storing, and processing facilities targeted by WS cooperative efforts. Depending upon the nature of the cargo process(es) at a respective facility, the integration of methods may vary. Public education efforts are integrated throughout all WS containment activities. This section summarizes the primary ports of exit at which WS works, and identifies key locations for containment activities on each facility.

4.1 Andersen Air Force Base

4.1.1 Andersen AFB Flight line

The Andersen Air Force Base (AFB) flightline supports all military air cargo activity for Guam and is a critical hub for military aircraft movement in the Pacific region. Andersen AFB supports all 4 service branches plus the U. S. Coast Guard. It also serves as cargo staging and consolidation area for deploying and transiting units. Inspections or all outbound items occur continuously; aircraft and cargo can move at anytime of the day and canine inspectors are available when needed. Aircraft are inspected at the start of each business day, if the aircraft departure is scheduled prior to 1800 the same day. Aircraft departing after 1800 are inspected within a 3 hour window prior to departure, as close as possible to departure time as feasible. Cargo staged on the flightline receives regular inspection (at least one per shift) until departure. A final inspection is conducted prior to loading. Trapping, toxicants, and spotlighting are used to control BTS populations on and around the flightline. Aircraft Hangers 1 thru 5, which are used as storage and operational bases for deployed units, are inspected by canine teams as needed.

4.1.2 734 Air Mobility Squadron Cargo Facilities

All outbound and transient military cargo passes through 734 Air Mobility Squadron (AMS) cargo facility or the Cargo Deployment Function Yard (CDF Yard) if items are too large for the cargo yard. Operations can occur around the clock in the facility and yard. Cargo staged in the facility or yard is inspected on a regular basis (at least one per shift) until departure. A final inspection is conducted prior to loading. Traps are placed on the perimeter wall of the cargo facility to intercept BTS in the area.

4.1.3 Transport Management Office Cargo Facility

The Transport Management Office (TMO) cargo containment facility processes military cargo of all descriptions. Inspections are coordinated with TMO management and conducted as required.

4.1.4 Petroleum and Oil Logistics, 36 Maintenance Squadron

This facility provides equipment and fuels for all aircraft using the Andersen AFB Flight Line. Tanker trucks provide fueling services for aircraft on the flight line, as needed. Trapping is done on the perimeter fencing of the facility as the petroleum products in the tanker trucks are deemed too hazardous for canine inspections.

4.1.5 HSC-25

HSC-25 is the Navy helicopter squadron based on Andersen AFB. Most operations are local, with one aircraft continuously on standby for Search and Rescue (SAR) operations. A daily inspection of the SAR designated aircraft is completed and inspections of other off-island missions are completed as needed. Other Navy units also operate from HSC-25, and inspections are conducted as required.

4.1.6 Northwest Field

Northwest Field supports exercises of various size and scope on an irregular basis. Close coordination with units that train there is necessary as there is no long-term BTS control in the area, thus increasing the risk of BTS departures. Inspections occur on site at Northwest Field during cargo build-ups and may receive further inspections as items are transported to the Andersen AFB flightline for their eventual departure.

4.1.7 Munitions Storage Areas One and Two

Munitions Storage Areas One and Two (MSA One and MSA Two) are the primary storage areas for U. S. Air Force munitions. Munitions destined for transportation off–island and not associated with a bombing mission are inspected prior to loading and departure. The size of shipments vary, but a canine inspection team is always on hand during the loading and to ensure containers are sealed nightly until the final seal is put on the completed container. Coordination and scheduling for inspections are is conducted through 36 Munitions Squadron. Wildlife Services has operated a large-scale BTS control project in MSA One for over 10 years; the primary goal of the project is to protect native birds and bats that use MSA One. A secondary benefit of the project is reduced risk of BTS incursion into munitions shipments.

4.1.8 DoD Exercises, Transient Units, and Irregular Movements

An unpredictable amount of irregular export activities, including DOD training exercises, Marine Expeditionary Unit visits, and other cargo movements occur on Andersen AFB property. Typically, containment in support of these events is coordinated through the unit command in charge of the activity. Containment strategies depend upon the scope and duration of the activity, and WS implements appropriate measures (including canine inspection, trapping, education, etc.) based upon the anticipated magnitude of the activity. The risk of BTS incursion is considered when planning locations and processes for cargo staging locations, wash-down sites, and other deployment-related activities.

Materials and supplies from off-island contractors, particularly associated with construction projects, are also subjected to canine inspection and/or other containment activities. These movements are irregular and may originate from a variety of locations around Andersen AFB property. Nearly all of these movements are consolidated in the 734 AMS cargo facility, the CDF Yard, or elsewhere on the Andersen AFB flightline.

4.1.9 Joint inspections transported through Andersen AFB
A significant amount of materials originating from Naval Base Guam are transported as air cargo on U.S. Air Force aircraft departing from Andersen AFB. This cargo includes munitions, mechanical equipment, and support materials for small units such as the Explosive Ordnance Disposal. Cargo typically passes through the 734 AMS Yard or the CDF Yard. All cargo departing from Andersen AFB is inspected by detector dog teams and falls under the jurisdiction of the 36 WGI 32-7004 Brown Treesnake Management.

4.2 Naval Base Guam

4.2.1 Warehouse 9
Warehouse Nine is the primary staging and consolidation facility for cargo and equipment used to re-supply naval vessels, as well as outbound household goods and general cargo. Inspections of all outbound cargo held inside the warehouse are conducted at least once daily, Monday through Friday. Follow-up inspections are conducted as needed, when arriving cargo is scheduled for immediate containerization. Cargo is generally not containerized on weekends and therefore, inspections are not completed on Saturday or Sunday. Larger equipment, to be shipped breakbulk, is staged at various locations around the wharf surrounding Warehouse 9. Shipments of this nature are inspected daily, and immediately prior to planned loading.

4.2.2 POV lot
Military members, including non-Navy personnel, who are changing duty stations, process their outbound personally-owned vehicle (POV) through the POV lot on Navy Main Base. A contractor containerizes the vehicles on site, for commercial surface shipment via the Port Authority of Guam. Inspections of vehicles scheduled for containerization are conducted daily at the POV lot, Monday through Friday, and on weekends as requested by the contractor.

4.2.3 MSC
The Military Sealift Command (MSC) consolidates general support cargo for Naval vessels. Canine inspections of outbound cargo are conducted at MSC daily, Monday through Friday, as needed.

4.2.4 Polaris T-Shed and Building 4450
The T-Shed and Building 4450 at Polaris Point are the primary loading points for cargo destined for the USN Frank Cable. Other vessels, including submarines, receive cargo from Polaris Point facilities, and munitions transported from the Naval Munitions Site (specifically torpedoes) are loaded at Polaris Point. Commodities loaded here are inspected as required, immediately prior to loading.

4.2.5 Naval Housing
Household goods for Navy members and civilian residents are wrapped and crated on-site at the individual residence on all Navy housing installations, as well as in private housing throughout Guam. Three companies, Dewitt, CargoNet, and Pacific Island Movers, are responsible for all household goods moves on DoD property; most crated household goods moves are trucked to commercial warehouses in the Harmon Industrial Park for containerizing, with a small volume of pack-outs moving through Warehouse 9. Wildlife Services obtains daily pack-out schedules directly from Navy Personal Property and conducts canine inspections of household goods

during the packing process, prior to crating. Follow-up inspections on packed crates and the containers that will be packed with military household goods are conducted at the individual commercial warehouses in the Harmon Industrial Park.

4.2.6 Kilo Wharf

Kilo Wharf is the primary loading point for all munitions transported by vessel. Munitions are either consolidated or containerized in the Naval Munitions Site or the Munitions Storage Area at Andersen Air Force Base, or they are staged on pallets at Kilo Wharf for direct on-board loading. Munitions that are consolidated away from Kilo are inspected prior to containerization; those staged at Kilo Wharf are inspected on-site prior to loading. Canine inspections occur as needed, Sunday through Saturday.

4.2.7 X-Ray Wharf

X-Ray Wharf is the primary location for staging and consolidating dry goods and cold storage goods that support Naval vessels. Inspection of dry goods occurs as needed, immediately prior to loading on-board. Because refrigerated commodities are unlikely to support a live BTS, inspections are not conducted on cold storage cargo. Canine inspections are generally conducted as loading is occurring, typically Monday through Friday, but occasionally on weekends as well.

4.2.8 DoD Exercises, Transient Units, and Irregular Movements

An unpredictable amount of irregular export activities, including DoD training exercises, Marine Expeditionary Unit visits, and other cargo movements occur on Navy property. Typically, containment in support of these events is coordinated through the unit command in charge of the activity. Containment strategies depend upon the scope and duration of the activity, and WS implements appropriate measures (including canine inspection, trapping, education, etc.) based upon the anticipated magnitude of the activity. The risk of BTS incursion is considered when planning locations and processes for cargo staging locations, wash-down sites, and other deployment-related activities.

Materials and supplies from off-island originating contractors, particularly associated with construction projects, are also subjected to canine inspection and/or other containment activities. These movements are irregular and may originate from a variety of locations around Navy property.

4.2.10 Joint inspections transported through Andersen AFB

A significant amount of materials originating from COMNAVMAR are transported as air cargo on U.S. Air Force aircraft departing from Andersen AFB. This cargo includes munitions, mechanical equipment, and support materials for small units such as the Explosive Ordnance Disposal. Cargo passes through the Air Mobility Squadron 734th inspection yard or the Cargo Deployment Function Yard. All cargo departing from Andersen AFB is inspected by detector dog teams and falls under the jurisdiction of the 36 WGI 32-7004 Brown Treesnake Management.

4.3 Guam International Airport

The Guam International Airport Cargo Facility is the primary staging and consolidation facility for cargo for outbound general cargo and supports all of the major international airlines that operate from Guam. Inspections of all outbound cargo held inside the warehouse are conducted at least once daily, Monday through Sunday. Follow up inspections are conducted as needed, when arriving cargo is scheduled for immediate containerization or loading.

Aircraft departing the Guam International Airport are inspected on a continuous basis, with all aircraft heading to high risk destinations targeted. To reduce BTS populations at the airport, and the subsequent risk of incursion into cargo and aircraft, BTS traps encircle the airport perimeter fence and are installed throughout forested environments inside the flight line. Nighttime spotlight searches are conducted nightly.

4.4 Packing and Shipping Companies

General surface freight and civilian household goods moves are handled by approximately 30 private freight forwarding companies located throughout central Guam. These companies American Moving, Lueng Fung, Jae Hoon, Marianas Steamship, Ambyth, Pepsi, CTSI, GTW, Dewitt, J.L. Baker, Black Construction, Triple B Forwarders, Kweks/Guam Couriers, Dick Pacific, DGX, Pacific Island Movers, U.S. Post Office, Micronesian Brokers Inc., FEMA, J.C. Marketing, NAPA, Net Cargo, Triple J Shipping, Foremost, Mid Pac, Duty Free, Conwood, Ambros, Home Depot, and Payless Distribution Center.

General freight is usually consolidated and containerized on-site at each of these freight forwarding companies. A subset of these companies also handles air freight, which is generally consolidated for final shipment at the Won Pat International Cargo Facility. Wildlife Services conducts daily canine inspections, as needed, for both commercial air and surface freight prior to final containerization for shipment. Household goods are wrapped and crated on-site at the individual residence and subsequently trucked to commercial warehouses in the Harmon Industrial Park for containerizing. Wildlife Services obtains daily pack-out schedules and conducts canine inspections of household goods during the packing process, prior to crating. Follow-up inspections on packed crates and the containers are conducted at the individual commercial warehouses in the Harmon Industrial Park. Snake traps are placed inside security fences at all commercial freight forwarding facilities.

4.5 Port Authority of Guam

All commercial surface cargo exported from Guam departs via the Port Authority of Guam (PAG). Most cargo arrives at the port already consolidated and/or containerized, having been handled by the roughly 30 private freight forwarding companies described above. A smaller volume of freight is consolidated on-site at PAG; Personally Owned Vehicles (POVs) are staged at PAG between the main entrance to the PAG Yard and the Port Police Headquarters building and are inspected daily before being loaded. Other miscellaneous freight, including portable gas tanks, containers that are scheduled for departure on the dock near Warehouse #2, and containers within the storage yard are inspected daily. Most outbound freight is staged at Warehouse #2, where palletized and break-bulk items that are destined for shipment off island are processed
.

Traps at PAG are placed along the chain link fences that encircle and in some cases bisect the active operations area. Snake traps are also placed along the fence on the south side of the container yard, eastward along the fence, encircling the east end of PAG, where excess containers are stored, and newly arrived vehicles are staged before delivery. Where there is jungle nearby, snake traps have been staggered along the fence with traps that have been placed within the jungle edge.

EXHIBIT M

U.S. Fish & Wildlife Service

News Release

Pacific Islands Fish and Wildlife Office
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For Release: September 29, 2015
Contact: Christine Ogura, 808-282-9442 or christine_ogura@fws.gov

U.S. Fish and Wildlife Service Protects 23 Species in Guam and CNMI Under the Endangered Species Act

The U.S. Fish and Wildlife Service (Service) is listing 23 species of plants and animals on Guam and the Commonwealth of the Northern Mariana Islands (CNMI) as threatened or endangered. The Service is not proposing critical habitat for these species at this time.

The Service identified 16 species of plants and animals as endangered, including the Mariana wandering butterfly, Langford's tree snail, and the Mariana subspecies of the Pacific sheath-tailed bat. These 16 species are at risk of extinction because of habitat loss and degradation related to development and other activities, the effects of nonnative species (*i.e.*, through habitat degradation, predation, and herbivory), and vulnerability as a consequence of reduced population size and distribution. Seven plant species are identified as threatened, including four species of orchid and a cycad (*Cycas micronesica*).

"These 23 species are facing tremendous challenges with shrinking habitat and the onslaught of invasive species," said Kristi Young, the Service's acting field supervisor for the Pacific Islands Fish and Wildlife Office. "Most of these species are known only to Guam and CNMI. It's imperative we continue to work with Guam and CMNI leadership, federal agencies, and our partners to save these important plants and animals."

The Service re-evaluated the proposed status for several plant species based on new data received from CNMI Department of Land and Natural Resources biologists and the public during the comment periods. The Service changed the status of five plants from endangered to threatened because the information revealed that the species were not as diminished as previously thought.

Critical habitat for these species is not determinable at this time because more time is needed to analyze the best available scientific data to identify areas appropriate for such a designation. The Mariana Islands covered by this listing rule are Guam, Saipan, Tinian, Aguiguan, Rota, Anatahan, Sarigan, Guguan, Alamagan, Pagan, and Asuncion.

- Five plants are endemic to the island of Guam – *Eugenia bryanii*, *Hedyotis megalantha* (pao dedu, pao doodu), *Phyllanthis saffordii*, *Psychotria malaspinae* (aplokating, palaoan), and *Tinospora homosepala*.
- Eight plants are known from both Guam and the CNMI – *Bulbophyllum guamense* (siboyas halumtanu, siboyan halom tano), *Dendrobium guamense*, *Heritiera longipetiolata* (ufa-halumtanu, ufa halom tano), *Maesa walkeri*, *Nervilia jacksoniae*, *Solanum guamense* (biringenas halumtano, birengenas halom tano), *Tabernaemontana rotensis*, and *Tuberolabium guamense*.
- One plant, *Cycas micronesica* (fading, faadang), occurs in Guam, the CNMI, Palau and Yap.
- Three animals are island endemics – the Guam tree snail (*Partula radiolata*; akaleha, denden) is endemic to Guam, the Rota blue damselfly (*Ischnura luta*, dulalas Luta, dulalas Luuta) is endemic to Rota, and Langford's tree snail (*Partula langfordi*; akaleha, devdev) is endemic to Aguiguan.
- The remaining six animals are historically known from both Guam and the CNMI – the Pacific sheath-tailed bat (*Emballonura semicaudata rotensis*; payeyi, paischeey), Slevin's skink (*Emoia slevini*; gualiik halumtanu, gholuuf), the Mariana eight-spot butterfly (*Hypolimnas octocula marianensis*, ababbang, libweibwogh), the Mariana wandering butterfly (*Vagrans egistina*), the humped tree snail (*Partula gibba*; akaleha, denden), and the fragile tree snail (*Samoana fragilis*; akaleha dogas, denden).

The final rule will publish in the Federal Register on Oct. 1, 2015. Comments received on the proposed rule and other supporting information are available at www.regulations.gov. The docket number for this rulemaking is FWS–R1–ES–2014-0038. For more information on these species and the final listing, visit http://www.fws.gov/pacificislands/.

The U.S. Fish and Wildlife Service works with others to conserve, protect, and enhance fish, wildlife, plants, and their habitats for the continuing benefit of the American people. For more information, visit www.fws.gov/pacific, or connect with us through any of these social media channels at facebook.com/USFWSPacific, flickr.com/photos/usfwspacific/, tumblr.com/blog/usfwspacific or twitter.com/USFWSPacific.

- FWS -

EXHIBIT N

BEFORE THE SECRETARY OF THE INTERIOR

Tinian Monarch (*Monarcha takatsukasae*)
Photo by Eric VanderWerf, USFWS

PETITION TO LIST THE TINIAN MONARCH (*Monarcha takatsukasae*) AS THREATENED OR ENDANGERED UNDER THE ENDANGERED SPECIES ACT

December 11, 2013
CENTER FOR BIOLOGICAL DIVERSITY

Notice of Petition

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PETITIONER

The Center for Biological Diversity ("Center") is a non-profit, public interest environmental organization dedicated to the protection of native species and their habitats through science, policy, and environmental law. The Center is supported by more than 625,000 members and activists. The Center and its members are concerned with the conservation of endangered species and the effective implementation of the Endangered Species Act.

CENTER *for* BIOLOGICAL DIVERSITY *Because life is good.*

Submitted this 11th day of December, 2013

Pursuant to Section 4(b) of the Endangered Species Act ("ESA"), 16 U.S.C. § 1533(b); Section 553(e) of the Administrative Procedure Act, 5 U.S.C. § 553(e); and 50 C.F.R. § 424.14(a), the Center for Biological Diversity, Tara Easter, Tierra Curry, and Randy Harper hereby petition the Secretary of the Interior, through the United States Fish and Wildlife Service ("FWS," "Service"), to list the Tinian monarch (*(Monarcha takatsukasae)* as a threatened or endangered species.

FWS has jurisdiction over this petition. This petition sets in motion a specific process, placing definite response requirements on the Service. Specifically, the Service must issue an initial finding as to whether the petition "presents substantial scientific or commercial information indicating that the petitioned action may be warranted." 16 U.S.C. § 1533(b)(3)(A). FWS must make this initial finding "[t]o the maximum extent practicable, within 90 days after receiving the petition." *Id.*

EXECUTIVE SUMMARY

The Tinian monarch (*Monarcha takatsukasae*) is a small forest bird that only exists on Tinian Island, a small island in the Commonwealth of Northern Mariana Islands (CNMI) in the western Pacific Ocean, east of the Philippines and south of Japan. This flycatcher was originally protected as an endangered species in 1970 (35 FR 08491) due to habitat loss resulting from agriculture and military activities prior to and during the Second World War. It was reclassified from endangered to threatened in 1987 (52 FR 10890), and in 2004 was delisted due to presumed recovery (69 FR 56367). Unfortunately, the Tinian monarch is once more threatened with extinction. The species experienced a rangewide decline of 39 percent from 1996-2008 and its very limited habitat faces multiple threats.

The Tinian monarch is considered to be threatened by the International Union for Conservation of Nature (IUCN 2012). It warrants protection as threatened or endangered under the Endangered Species Act due to threats from four of the five listing factors under the ESA ((16 U.S.C. § 1533 (a)(1)):

Loss and Degradation of Habitat:

The monarch's remaining habitat in its tiny range is threatened by multiple factors including an increase in U.S. military activities on Tinian, the Tinian Airport expansion and alterations to the Federal Aviation Administration Mitigation Area, clearing of forests for agriculture, human population growth and development, fire, and increased vine cover which may reduce suitable nesting habitat. When the monarch was delisted, an area was set aside to provide high quality habitat to ensure its persistence. Even this area, however, is now under threat from proposed military activities and other factors. The monarch's limited habitat is threatened by degradation from military training on the island including proposed firing ranges and combat training zones that will encroach into forested land and disturb surrounding areas. Only 549 acres of native limestone forests (five percent of the island) remain on Tinian, which is where the highest densities of monarchs exist. Monarchs have far greater nesting success in remnant native forest, probably due to the greater availability of insects and greater protection from fire and storms (Balis-Larsen and Sutterfield 1997, BirdLife International 2013). Camp et al. (2012, p. 292) identify habitat loss and degradation, such as the expansion of the Tinian airport, as one likely cause of the significant decline in monarch abundance since 1982. The monarch has declined in areas on Tinian where housing, roads, and services have expanded, and it is expected that the downward trend will continue with increasing development (Camp et al. 2012, p. 295). Protection for the monarch is urgent because forest clearing on Tinian for military activities is underway. For example, a news release dated December 6, 2013 states, "In four weeks, those Marines took a jungle and restored it into four runways" (Rubio 2013).

Disease and Predation

The Tinian monarch is threatened by predation from and competition by introduced rodents on Tinian. Estimates of rat densities on Tinian are among the highest ever recorded on tropical Pacific islands (Wiewel et al. 2009, p. 214). The threat of invasion by the predaceous brown tree snake from Guam is also very high with increased cargo transport between islands, and there have already been multiple, but unconfirmed, sightings on Tinian. Monarch population declines of 30 to 49 percent are projected in the likely event of the brown tree-snake becoming established on Tinian (BirdLife International 2013). The monarch is also threatened by predation from feral and domestic cats. Predation has been identified as a likely factor in the recent declines in monarch abundance (Camp et al. 2012).

The monarch is also threatened by disease including avian poxvirus. Thirty-nine percent of monarchs mist-netted in 2006 and 11 percent of monarchs mist-netted in 2007 displayed cutaneous lesions. Cutaneous lesions resulting from pox viruses interfere with normal behavior and can lead to weakness, emaciation, and difficulty seeing, breathing, feeding and perching (USGS 2013).

Inadequacy of Existing Regulatory Mechanisms

There are no regulatory mechanisms that adequately protect the Tinian monarch. It was delisted under the ESA in 2004, and was removed from CNMI's list of threatened and endangered species in 2009. The Post Delisting Monitoring Plan (PDMP) for the Tinian monarch expired in 2010. The final report summarizing the results of the monitoring effort has yet to be published. No further monitoring in accordance with the PDMP is known to be occurring.

Other Factors

The Tinian monarch is threatened by the effects of climate change including rising sea levels, increased storm events, and increased risk from stochastic weather events such as fires and droughts. Inclement weather is one of the primary causes of monarch nestling mortality (Balis-Larsen and Sutterfield 1997).

The monarch is exceedingly vulnerable to extinction due to its highly restricted range on a single small island. Due to these threats, the Tinian monarch warrants protection under the Endangered Species Act.

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INTRODUCTION

The Tinian monarch is a small forest bird that only exists on Tinian Island. The flycatcher has undergone decline in both abundance and historical range and needs Endangered Species Act protection in light of ongoing and future threats to its survival. This petition summarizes the information available on the natural history of the Tinian monarch, the conservation and population status of the species, and the threats to the monarch and its habitat. The petition shows that, in the context of the ESA's five statutory listing factors, the Tinian monarch warrants protection as endangered or threatened under the Act due to loss or curtailment of habitat or range, disease and predation, the inadequacy of existing regulatory mechanisms, and other factors including noise pollution and global climate change.

NATURAL HISTORY

Taxonomy and Nomenclature

The Tinian monarch was first recognized as an individual species by Yamashina in 1931 (cited in USFWS 1999). Its complete classification can be found in Table 1. The Tinian monarch is known as the Chuchurican Tinian in the Chamorro language on Tinian Island (USFWS 2005 p. 1).

Table 1: Taxonomic Classification of the Tinian Monarch (BirdLife International 2012).

Kingdom	Phylum	Class	Order	Family	Genus	Species
Animalia	Chordata	Aves	Passeriformes	Monarchidae	Monarcha	Takatsukasae

Description:

The Tinian monarch is a member of the monarch flycatcher family of forest birds. Adults stand at about 15 cm (6 in) tall and have light rufous under parts, olive-brown upper parts, and dark brown wings and tail (Baker 1951, cited in USFWS 1999 p. 8533). The sides of the face are buffy-tan and the crown and nape are grey. The monarch has a bold eye-ring, two narrow wing-bars and white-edged tertial feathers. The rump and under tail coverts are also white (BirdLife International 2013). The monarch has a short two-note call that sounds like a squeaky dog toy. Its song is a loudly whistled *tee-tee-wheeo,* and it also produces a loud, raspy scold (BirdLife International 2013).

Breeding:

The Tinian monarch is thought to breed year round, and peak nesting periods may be associated with increased rainfall (USFWS 1998, p. 7). There appears to be distinct seasonality in nesting activity and success, with little nesting occurring during periods of low rainfall (Balis-Larsen and Sutterfield 1997). Nesting success is higher in areas of native forest than in other habitats (Ibid.).

Habitat Requirements:

The Tinian monarch is a forest bird that lives mostly in native limestone forest dominated by figs (*Elaeocarpus joga, Mammea odorata, Guamia mariannae, Cynometra ramiflora, Aglaia mariannensis, Premna obtusifolia, Pisonia grandis, Ochrosia mariannensis, Neisosperma oppositifolia, Intsia bijuga, Melanolepis multiglandulosa, Eugenia* spp., *Pandanus* spp., *Artocarpus* spp., and *Hernandia* spp.). It can also be found in secondary vegetation consisting of *Casuarina equisetifolia,* as well as non-native species (*Acacia confusa, Albizia lebbeck, Cocos nucifera, Delonix regia*) with some native species mixed in, and in nearly pure strands of introduced tangantangan, a shrubby legume (USFWS 2005 p. 1-2). The monarchs forage and nest within the native limestone forests, secondary vegetation, and introduced tangantangan habitats. Higher densities, higher rates of reproductive success and smaller home ranges within the native limestone forests indicate that the native forests provide higher quality habitat for the monarch than other habitat types (USFWS 2005 p. 2; Department of the Navy 2010 3:10-5).

Point transect sampling for Tinian monarch densities (birds/ha) based on habitat type were conducted in 2008 by USFWS. Table 2 summarizes the results showing the highest density estimates in limestone forest, followed by secondary forest.

Table 2: Tinian monarch density estimates (birds/ha), standard error (SE), and 95% confidence intervals (Lower and Upper 95% CI) by habitat in 2008 based on point transect sampling (USFWS 2009, p. 234, Table 3).

Habitat	Estimate	SE	L 95% CI	U 95% CI
Agriculture	1.75	1.75	*	*
Limestone Forest	6.41	0.74	5.09	8.05
Open Field	2.83	0.64	1.81	4.44
Secondary Forest	5.82	0.54	4.84	7.01
Tangantangan Thicket	4.36	0.47	3.52	5.39
Urban/Residential	1.50	1.04	0.32	6.94

*Sample size was insufficient to estimate reliable confidence intervals.

Current and Historic Distribution

The Tinian monarch lives only on Tinian Island which is a 101 km^2 (39 mi^2) island in the Northern Marianas, three islands north of Guam (USFWS 1999). The monarch is endemic to Tinian, though a population may once have existed on Saipan (Peters 1996, cited in USFWS 2005, p.1). The Tinian monarch relies on forested habitats for its nesting and foraging behaviors. Tinian Island experienced a rapid change in vegetation as the human population grew, especially throughout the 20th century. The introduction of European-based agriculture and ranching practices, massive sugar cane production, and the development of military bases by the Japanese and then the United States has removed much of the native vegetation that formerly provided monarch habitat (reviewed in Camp et al. 2012, p. 283-284). Today, there are only 549 acres of native forests that remain, which make up about five percent of the island (Camp et al. 2012, p. 2).

Conservation Status

The Tinian monarch is ranked by the International Union for Conservation of Nature (IUCN, 2012) as "Vulnerable," one of the three levels in the "Threatened" category. As defined by the IUCN, a ranking of Vulnerable means that the best available evidence indicates that the taxon is considered to be facing a high risk of extinction in the wild (see: http://www.iucnredlist.org/static/categories_criteria_3_1). The justification for the Vulnerable (Threatened) ranking for the monarch includes its tiny range, the high risk of brown tree-snake invasion, and vulnerability to stochastic events such as typhoons because the monarch is confined to a single small island. The IUCN ranking states that due to suspected population decline, the monarch may warrant uplisting to Endangered if population declines are confirmed. Camp et al. (2012) report a statistically significant decline in monarch abundance, with both temporal and spatial declines in monarch density (p. 288), indicating that the monarch's status warrants uplisting.

Population Status

In 1970, when the monarch was listed as endangered by the U.S. Fish and Wildlife Service, it was presumed that population numbers had declined from historical levels due to widespread destruction of habitat by agriculture and military activities, especially after WWII. No surveys had been conducted to assess the bird's status, and loss of habitat was used as a proxy for population decline (USFWS 1999, p. 8534). In the 1980s, Reichel and Glass (1991) noted that the Tinian monarch was "abundant" meaning that the monarch was almost certain to be found within representative habitats and in relatively large numbers (Camp et al. 2012, p. 284). In 1982, the first range-wide survey for the Tinian monarch was conducted by the U.S. Fish and Wildlife Service. A point transect count/variable circular plot survey yielded a population estimate of 39,338 (this estimate was later adjusted, see Table 3, below) (USFWS 2009, p. 228). The results of this survey led to downlisting of the monarch from endangered to threatened status in 1987 (52 FR 108900). In 1996, another survey was conducted using the same methods as the 1982 survey, and the estimated population was 55,721, though this estimate too was later re-adjusted (Lusk et al. 2000, p. 186, USFWS 2009, see Table 3, below). Following this apparent increase in numbers, the Service proposed to delist the monarch in 1999 (64 FR 8533), and it was delisted in 2004 (69 FR 56367).

The USFWS designed a 5 -Year Post-Delisting Monitoring Plan (PDMP) for the Tinian monarch in 2005 and published a progress report in 2009. The PDMP's objectives were to monitor the population status of the Tinian monarch and the use and abundance of the forested habitat it relies on, and to establish protocols for early detection of possible brown tree snake introductions to the island (USFWS 2005, p. 4). The monitoring was to be conducted regularly from 2006-2010 using road-side point counts, small scale study plots, and an island-wide VCP survey at the end of the 5-year monitoring plan (USFWS 2005, p. 6). However, the Commonwealth of the Northern Mariana Islands' Division of Fish and Wildlife (CNMI DFW) has not continued counts of the Tinian monarch since the initiation of the plan in 2005 (Marshall and Amidon 2009, p. 3).

The U.S. Navy has conducted quarterly point counts on seven transects in native limestone forest since 1999, but because these only account for a small portion of the monarch's range, they do not provide an accurate estimate of overall population status (Marshall and Amidon 2009, p. 3).

The Navy's early warning detection plots were designed for the monitoring and prevention of brown tree snake invasion and have been used to measure the density, territory sizes, and survival rates of the Tinian monarch (Marshall and Amidon 2009, p. 3). Within these native forest plots, territory sizes have appeared to remain relatively stable, suggesting that the densities of monarchs in these preferred habitats may not have changed much from 1995-2009 (Marshall and Amidon 2009, p. 6). In terms of survival, the survival rate from 2006-2009 was measured at 82 percent for males and 64 percent for females. Though some banded birds may have just relocated rather than succumbed to mortality, the low female survival rates are a cause for concern (Marshall and Amidon 2009, p. 4).

In 2008 the Pacific Islands Fish and Wildlife Office conducted an island-wide survey for the Tinian monarch using the same point transect/variable circular plot methods used for the 1982 and 1996 surveys, and re-analyzed the data from 1982 and 1996 to account for improvements made in the model used and the program DISTANCE (USFWS 2009, p. 228, 235). Improved estimates from 1982 and 1996 as well as the most recent estimate from 2008 are shown in Table 3.

Table 3: Population density (birds/km2 ± SE, with 95% CI) and abundance (density times the area of Tinian; 101.01 km2; with 95% CI) estimates for Tinian monarchs from three point transect surveys (taken from USFWS 2009, p. 233).

Year	Density	Abundance
1982	634.5 ± 37.88 (564.3–713.4)	60,898 (49,484–75,398)[1]
1996	705.7 ± 43.96 (624.3–797.6)	62,863 (50,476–78,758)[2]
2008	431.3 ± 30.75 (374.9–496.2	38,449 (29,992–49,849)

[1] 39,338 (35,161–43,515), Engbring et al. (1986) – Estimate from original report
[2] 55,721 (48,345–63,495), Lusk et al. (1986) – Estimate from original report

Using standardized methodology, the 2008 data show a 37 to 39 percent decline in the Tinian monarch population from 1982 and 1996 to 2008 (USFWS 2009, p. 233).

THREATS

The Tinian monarch warrants protection as an endangered or threatened species under the Endangered Species Act. In the 2005 PDMP, the USFWS states that "if data from this monitoring effort or from some other source indicate that the Tinian monarch is experiencing significant declines in abundance or distribution, that its survival or territory occupancy are declining significantly, or that it requires protective status under the Act for some other reason, the Service can initiate procedures to re-list the monarch, including, if appropriate, emergency listing" (USFWS 2005, p. 4-5). The bird's population has undergone decline (Camp et al. 2012), and in addition, new factors threaten the survival of the monarch.

A. The present or threatened destruction, modification, or curtailment of its habitat or range.

The Tinian monarch is threatened by habitat loss and degradation due to military activities, the Tinian airport expansion, waste facilities, human population growth, agriculture, fire, and increased vine cover.

I. Military Land Use

In 1944, the United States took control of Tinian from the Japanese and converted the island into a major airbase for the war on Japan (Camp et al. 2012, p. 284). When WWII ended, the military mostly abandoned the island, but the Department of Defense ("DoD") maintains leased land on Tinian for training purposes (Camp et al. p. 284). Current military training on the island occurs on the Tinian Military Lease Area, which encompasses 15,353 acres - with 7,574 acres in the northern third of Tinian in the Exclusive Military Use Area ("EMUA"), and 7,779 acres in the middle third of Tinian in the Leaseback Area ("LBA") (Department of the Navy 2010, 3: 2-4). Activities in these two areas consist of airfield training in the EMUA and small scale ground element training in the LBA (Department of the Navy 2010, 3: 2-4). Now, a proposal to move military training activities from Okinawa to Guam and Tinian presents a significant threat to the Tinian monarch's habitat by dramatically increasing the amount of activity and land use by the military.

Proposed activities for military training on Tinian include Rifle Known Distance Range (KD), Automated Combat Pistol/Military Police (MP) Firearms Qualification course, platoon battle course, and a field firing range (Department of the Navy 2010, 3: 2-1). The Tinian monarch inhabits 62 percent of the total land area on Tinian. Ninety-three percent of that area is made up of secondary vegetation and introduced tangantangan forest, and seven percent of it is native limestone forest. The Military Lease Area includes about 75 percent of current monarch habitat, which supports about 70 percent of the monarch population (Department of the Navy 2010, 3: 10-4).

In the Environmental Impact Statement for the Guam and CNMI Military Relocation, three alternatives were analyzed. The Record of Decision for the Guam and CNMI Military Relocation was signed in September 2010 and Alternative 1 was chosen as the Preferred Alternative. Based on density estimates made in 2009 by the USFWS, at least 204 monarch territories will likely be lost through construction (Department of the Navy 2010, 3: 4-35). Tables 4 and 5 summarize the potential impacts that military construction will have on the vegetation communities and Tinian monarch habitats with the implementation of Alternative 1. Though Alternative 1 is only estimated to directly impact one percent of the monarch population, the overall impact will be greater due to indirect effects of noise and disturbance and edge effects. The threat posed to the monarch's long-term survival is also heightened by the loss of additional forest when so little forested habitat is available on Tinian for the monarch.

Vegetation clearing and training activities are currently underway on Tinian (eg., see Defense Video and Imagery Distribution System 2013, Rubio 2013). In addition to outright habitat loss and degradation, training activities in the forest threaten to disrupt normal monarch feeding and reproductive behavior.

Table 4: Vegetation Removed (ac [ha]) within the Tinian MLA with Implementation of Alternative 1 (Department of the Navy 2010, 3: 10-14, Table 10.2-1.)

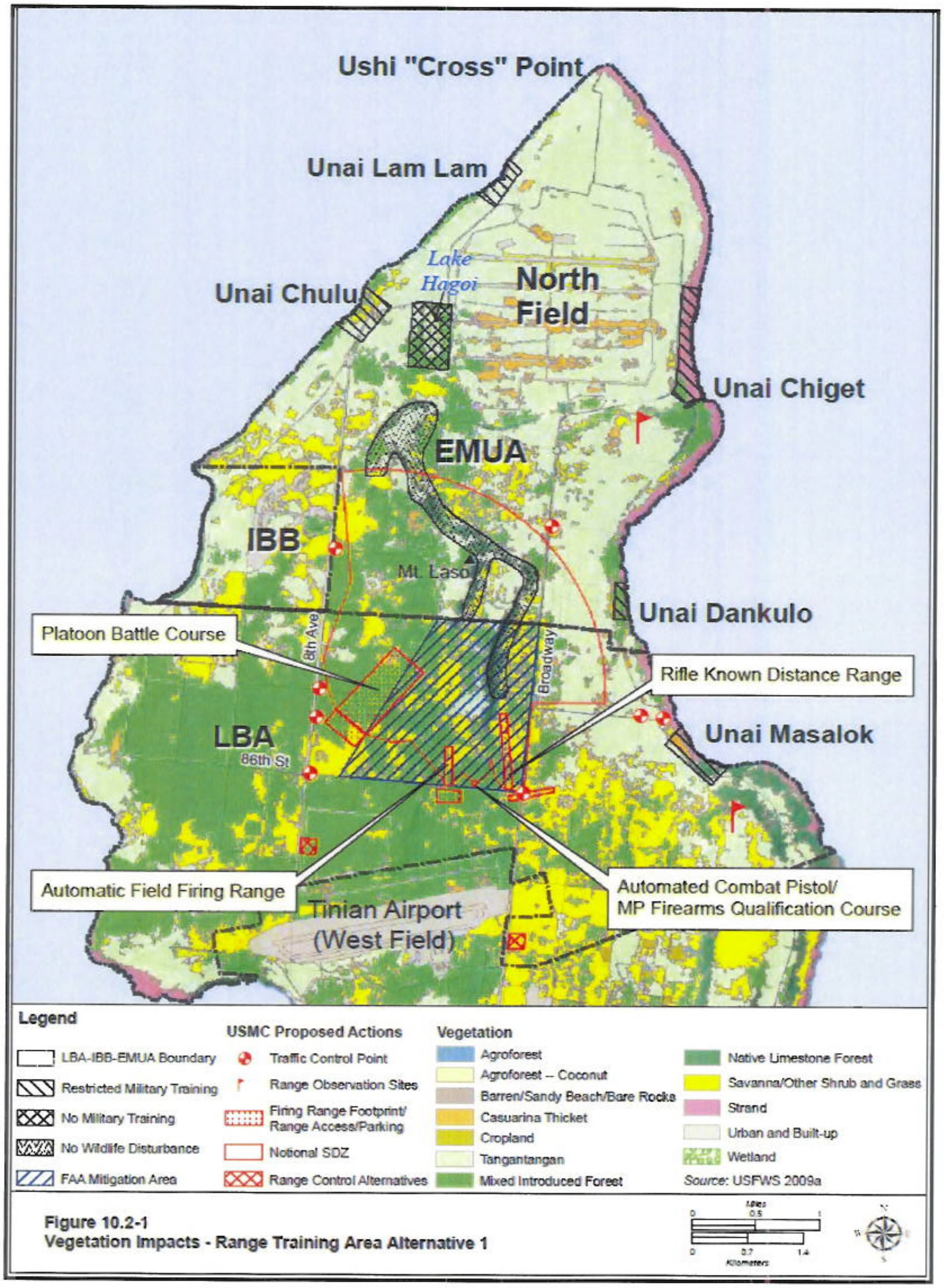
Parcel and Activity	*Mixed Introduced Forest*	*Tangantangan*	*Shrub and Grass*	*Developed*
Platoon Battle Course	123 (50)	0	13 (5.3)	0
Ranges	13 (5.3)	0	25 (10)	0
Range Control	9.0 (3.6)	0	9.8 (4.0)	1.0 (0.4)
Range Support Areas	28 (11)	0.8 (0.3)	19 (7.7)	0.4 (0.2)
Total area removed	**173 (70)**	**0.8 (0.3)**	**67 (27)**	**1.4 (0.6)**

Table 5: Direct Impacts to the Tinian Monarch with Implementation of Alternative 1 (Department of the Navy 2010, 3: 10-16, Table 10.2-2.)

Habitat Type	*Habitat Removed (ac [ha])*	*Monarch Density (#/ha)*	*Total Potential Birds in Removed Habitat*	*Max. Territories (#/ha)**	*Total Potential Territories in Removed Habitat*
Mixed Introduced Forest	173 (70)	5.82	407	2.9	203
Tangantangan	0.8 (0.3)	4.36	1	2.5	1
Totals	**174 (70)**	NA	**408**	NA	**204**

Legend: NA = Not Applicable.
Source: *USFWS 2009.

Figure 1: Vegetation Impacts – Range Training Area Alternative 1 (Department of the Navy 2010, 3:10-17, Figure 10-21)



Outside of the proposed ranges and battle course, ongoing and proposed field training of military personnel will occur in areas with limestone, secondary, and tangantangan forests where Tinian monarchs commonly nest (USFWS 1999b, p.28). Large scale training, lasting up to nine weeks a year, and small scale daily training is a threat to monarchs because of the potential to knock midlevel nests out of trees as soldiers move through forests (USFWS 1999b, p. 28). In 1999, the Service's Biological Opinion on the effects of the military proposals on the monarch determined that they were not likely to jeopardize the continued existence of the species. This opinion, however, was given before new information was published on the significant population decline of the bird (Camp et al. 2012; discussed in Population Status above). Due to new information on declines in the monarch's abundance, and due to the range of other threats facing the flycatcher including other causes of habitat loss, predation, disease, and global climate change, the Service should reconsider the impacts that these military training proposals will have on this endemic bird. Without Endangered Species Act protection, there is no regulatory mechanism in place to protect the monarch from military expansion and other threats which are cumulatively degrading its habitat.

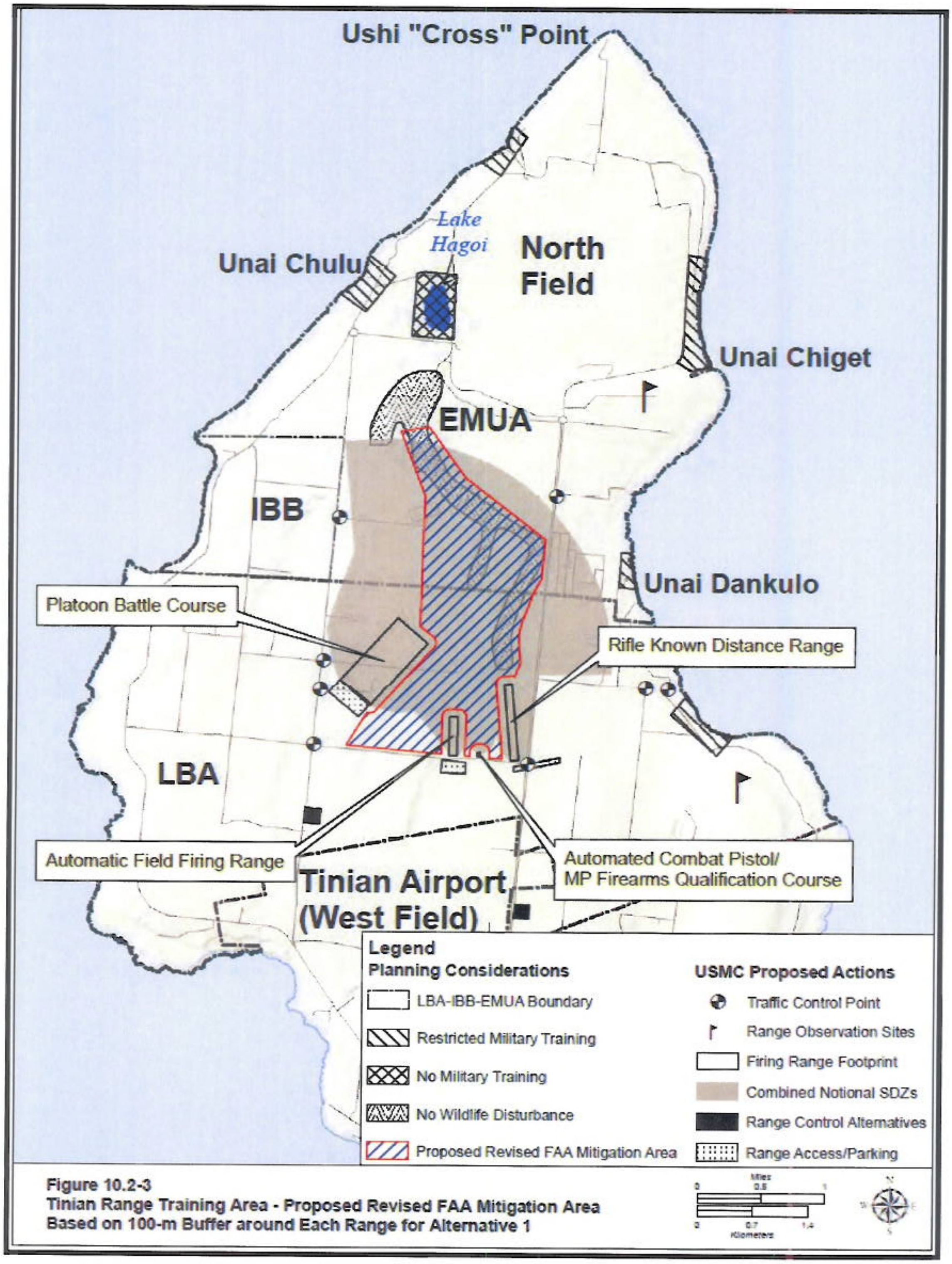
II. Tinian Airport Expansion and the Federal Aviation Administration Mitigation Area

In 1998, the CNMI and the Federal Aviation Administration (FAA) proposed an expansion to the West Tinian Airport to accommodate larger aircraft and an expected increase in foreign travelers due to the passing of the Tinian Casino Gaming Control Act of 1989 (USFWS 1998, p. 3). The expansion required construction on an additional 605 acres of land which involved clearing 405 acres of tangantangan and secondary forest (USFWS 1998, p. 3, 5). At the time of this proposal, the Tinian monarch was listed as threatened under the ESA, and the USFWS recommended that its status be reassessed in 1996 based on their current knowledge of the bird's population (USFWS 1998, p. 7). The project was estimated to adversely impact 1,103 monarchs, but based on the assumed increase in the monarch's population and increase in vegetation, the USFWS did not consider this project to be a serious threat to the monarch population (USFWS 1998, p. 9). The project began construction in 1999.

To compensate for the forest lost in the expansion of the West Tinian Airport, the FAA designated 936 acres of forest within the LBA (Military Leaseback Area) as the Airport Mitigation Conservation Area. This area is made up of 311 acres of medium value habitat and 625 acres of low value habitat (USFWS 1998, p. 5). The implementation of Alternative 1 of the military relocation will remove 70 acres of the FAA Mitigation Area that was set aside to protect the monarch. The destruction of this land does not comply with the requirements laid out in the "Dedication of Tinian Military Retention Area Land for Wildlife Conservation" which was established for the protection of "endangered and threatened wildlife, particularly the Tinian monarch" with the provision that it is the right of the U.S. military to "use the premises for low-impact military training and for other purposes that do not disrupt the habitat and living conditions of the Tinian monarch" (Department of the Navy 2010, 3:10-16). Without Endangered Species Act protection, projects such as this one will continue to degrade the limited habitat the monarch depends on for survival, including habitats that had previously been set aside for the species.

To compensate for the designated mitigation habitat that will be lost, a different area will be added to the mitigation area, but this land is already protected, therefore it's substitution for the forested acres that will be degraded provides little actual benefit for the monarch. The proposed revised FAA Mitigation Area includes forested lands further north in the Mt. Lasso area which largely includes an area that is already designated as a "No Wildlife Disturbance" zone by CNMI (See Figure 2) (Department of the Navy 2010, 3:10-24, 10-25). Although this revision would add a significant amount of acreage to the mitigation area, the land proposed to be protected in the expansion is not under current threat of development and likely would not be in the future due to the steep nature of the limestone forest. Further, nearly the entire Mitigation Area would still be within the Surface Danger Zone (SDZ) of military training activities.

Figure 2: Tinian Range Training Area – Proposed Revised FAA Mitigation Area Based on 100-m Buffer around Each Range for Alternative 1 (Department of the Navy 2010, 3:10-25, Figure 10.2-3)



Given that the population of monarchs has already fallen below the estimated minimum number of 41,791 individuals that could be supported by the remaining available habitat as of 1999 (USFWS 1999, p. 8536; CNMI SWARS Council 2010, p. 13), it is reasonable to assume that even if the land disturbed in the Mitigation Area was replaced by formally protecting land elsewhere, there would not be enough remaining habitat to sustain a healthy population of Tinian monarchs in the long-term.

Because space on Tinian is so limited, pressures on the monarch's habitat will continue to build. The permitted destruction of part of the Airport Mitigation Conservation Area exemplifies why ESA protection for the monarch is necessary and warranted.

III. Agriculture

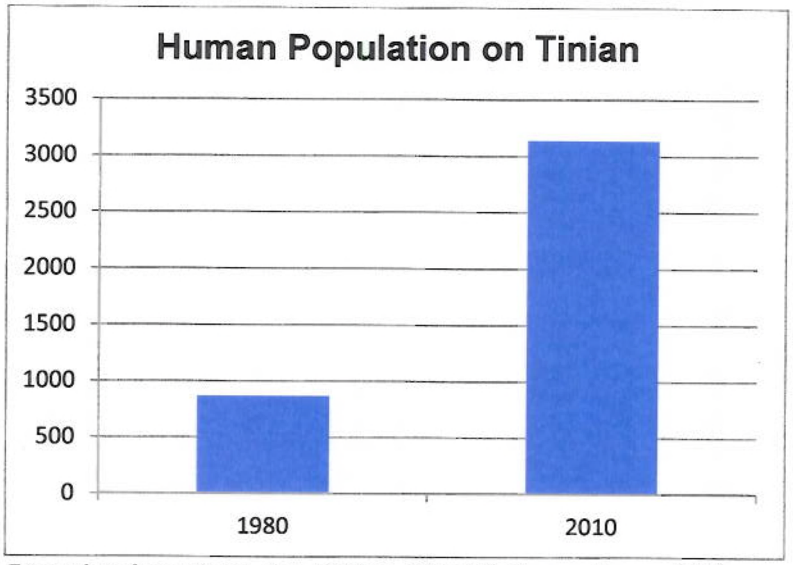
Loss of forested habitat due to clearing for agriculture contributed to the decline of the monarch historically. Different forms of agriculture swept through Tinian under Spanish, German, and Japanese control, converting the vast majority of the island to cropland before WWII (Camp et al. 2012, p. 283-284). Ranching of cattle, pigs, and goats began on the island in the 1500s, and over time dominant agricultural crops have included coconut plantations and sugarcane. After WWII, the United States took control of the island from Japan and the military occupied almost all of it. Now, most of the island (71 percent) that is leased to the U.S. military has had less agricultural use, but 30-50 percent of the island is still used for grazing, which partly shares space with military leased lands. Ten percent of the island is used for other forms of agriculture (USFWS 1999, p. 8534).

Ongoing forest clearance for cattle farming poses a threat to the monarch's remaining habitat (IUCN 2013). Cattle ranchers on Tinian have raised concerns about decreased grazing availability on military lands which could result from increased military activity on the island (Franklin 2013). Decreased availability of military lands could push ranchers to other parts of the island and further degrade remaining or potential monarch habitat. Trails created by cattle and goat grazing disturb natural habitat by accelerating erosion and impacting native vegetation (Department of the Navy 2010, 3:10-6). Feral ungulate populations have also grown on the island as a result of ranching practices, and they are damaging native forests by preventing regeneration and changing species composition (Sherley 2001, p. 44).

IV. Human Population Growth and Development

The human population on Tinian has rapidly increased since the 1980s (Figure 3), magnifying the development pressure on the monarch's limited habitat.

Figure 3: Human Population on Tinian from 1980 to 2010.



Data taken from: Camp et al. 2012, p. 295; U.S. Census Bureau 2010; USFWS 1999, p. 8534.

Population growth is mostly concentrated in the Carolinas region of the island, which includes San Jose. From 2000 to 2010, the total number of housing units on Tinian increased from 790 to 1,118 (USDI 2013). An influx of military personnel is expected to add an additional 5,600 people to Tinian's population from 2015-2035 (USDI 2013). The Tinian monarch has declined in these areas where houses, roads, and services have extended (Camp et al. 2012, p. 295). It is expected that the human population on Tinian will continue to expand as tourism and job opportunities increase under the provisions of the Tinian Casino Gaming Control Act of 1989 (see below) which will lead to development of additional facilities (see below).

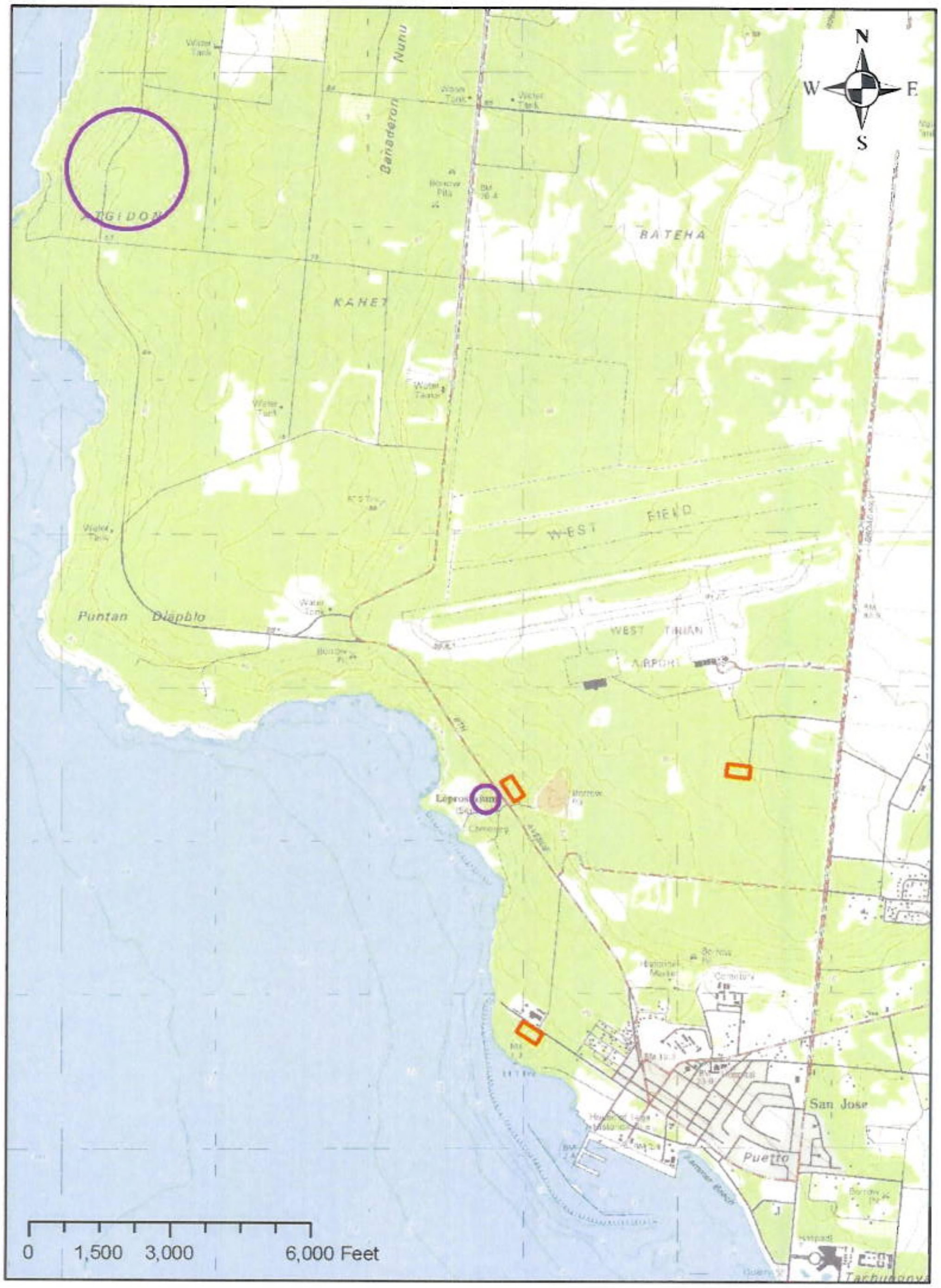
1. The Tinian Casino Gaming Control Act of 1989

The Tinian Casino Gaming Control Act of 1989, also known as the "Casino Initiative" was a push to increase foreign tourism and investment on the island (USFWS 1998, p. 3). Under this act, up to five casino licenses can be issued with the requirements of constructing a 300 room, 20,000 ft^2 gaming floor space casino/hotel facility per license. Four have already been issued, and one facility, the Tinian Dynasty Hotel and Casino, has been built and is fully operating (USFWS 1998, p. 3).

2. Waste Facilities

Proposed waste facilities, including a new landfill to replace the current dump and a solid waste transfer site, will remove mixed introduced forest and tangantangan habitat. The new landfill will be constructed on a 30-acre site at the Atgidon area (Tetra Tech 2013) which largely includes forested habitat that supports monarchs (see Figure 4).

Figure 4: Landfill site location and the three alternative transfer sites (Duenas, Camacho & Associates, Inc. 2012, p. 1-2; Figure 1-1)



The chosen site, Site C, will be a 3-acre property that requires clearing mixed introduced forest and tangantangan thicket where Tinian monarchs are known to reside (U.S. Department of the Interior 2013, p.3; Duenas, Camacho & Associates, Inc. 2012, p. 3-4, 3-8).

3. Wind Turbine Farm

The monarch is potentially threatened by the development of a wind turbine farm on Tinian. While increased wind energy production is desirable, especially given the threat posed to biodiversity globally from climate change, careful siting, use of best technology, and mitigation are critical in wind development to prevent harm to imperiled species such as the monarch.

A $200 million wind turbine farm to produce up 40-60 Megawatts of energy has been proposed for Tinian (Eugenio2013). Two potential locations for turbine farms on Tinian have been identified by CNMI. The first is located two miles east and one mile south of the Tinian Airport runway on a 300 ft elevation bluff (Baring-Gould et al. 2011, p. 32). The second is located on a broad plateau at 500 ft of elevation, southeast of San Jose (Baring-Gould et al. 2011, p. 33). Both sites are surrounded by native limestone, tangantangan, and mixed introduced forest which could be occupied by Tinian monarchs.

Wind farms present a number of concerning factors to birds including collision mortality, displacement due to disturbance and barrier effects (the altering of flyways or migration patterns to avoid wind farms), nest mortality, and habitat change or loss (Dewitt et al. 2006, Loss et al. 2013, Zimmerling et al. 2013). Precise estimates of impacts that turbines have on bird populations are largely unknown due to the variability of each farm and study methodologies, but passerines are thought to suffer the most collision fatalities (Kuvlesky et al. 2007, p. 2488). More than 80 percent of avian fatalities at wind turbine farms are passerines, likely because they fly at lower altitudes than other bird species (Mabee et al. 2006, p. 682; Erickson et al. 2002 cited in Kuvlesky et al. 2007, p. 2488). In addition to collision fatalities, many bird species may avoid foraging, nesting, and roosting habitats near wind farms during construction to avoid disturbance and noise (Band et al. 2007, Higgins et al. 2007, cited in Zimmerling et al. 2013).

In the absence of federal protection, numerous projects like the examples discussed above can be developed without consideration for the monarch, allowing its very limited habitat to be chipped away without consideration of cumulative impact. The rapid loss of forested land and increase in the human population and activity on Tinian due to military land use and agriculture were the main causes for listing the Tinian monarch as endangered in 1970 (50 FR 45632, cited in USFWS 1999, p. 8534). Although gross changes in forest cover are unlikely to have been the cause for the recent decline of the Tinian monarch population from 1982 to 2008 (USFWS 2009, p. 237), current plans for land use on Tinian present significant threats to the habitat and range of the monarch, necessitating federal listing. Incremental habitat loss, in conjunction with other threats such as disease and predation, have risen to the level of threat under the criteria of the ESA.

V. Fire

Both natural and intentional fires present a threat to the Tinian monarch's habitat (Balis-Larsen and Sutterfield 1997, BirdLife International 2013). Natural fires occur regularly during the dry season and have cleared up to 200 acres a year. Military weapons usage and other activities during dry seasons increase this risk (Department of the Navy 2010, 3:10-21). Additionally, many wildfires are caused by intentionally set fires going unattended and spreading. Hunters in particular burn grassland to induce new grass sprouts which attract deer, and sometimes unintentionally burn parts of forest. Many of these cases go unreported because the public is unaware of the damage that it causes (CNMI SWARS Council 2010, p. 20).

VI. Increased Vine Cover

The Service noted that gross changes in the amount of available forest cover were unlikely to have been a cause for the decline in the Tinian monarch population from 1996 to 2008, but that the majority of the forest had an increase in vine cover, which may reduce the available areas for nests and territories (USFWS 2009, p. 237). Increasing vine cover is an emerging problem in tropical forests. Eight studies on the state of woody vines in tropical forests in the Americas showed that vines were increasing in abundance and biomass (Khan 2011). Vines are better adapted to survive in low water conditions, so they grow faster than trees during the dry season and out-compete them for light and water (Khan 2011). This lowers the survival rate of trees and presents a threat to the health of Tinian's forests.

The present and future threats to the Tinian monarch's habitat and range are causes for high concern for the survival of this rare island bird. Due to the magnitude and imminence of these threats, the monarch warrants protection under the Endangered Species Act.

B. Overutilization for commercial, recreational, scientific, or educational purposes.

There are no data which indicate that the Tinian monarch is currently threatened by overuse as it is not known to be sought after for any scientific, educational, recreational or scientific purpose (USFWS 1999, p. 8536).

C. Disease or Predation.

The Tinian monarch is threatened by disease due to the spread of avian pox virus. When the USFWS proposed delisting the Tinian monarch in 1999, there were no indications that disease was a threat to the monarch or other avian species on Tinian (USFWS 1999, p. 8536). In 2006, while mist netting and banding monarchs within the three "early warning plots" created for the PDMP, 39 percent of monarchs caught were found to have lesions on their feet and toes, and in 2007, 11 percent of birds caught had them as well (Marshall and Amidon 2009, p. 6). Although the clinical tests on the lesions were inconclusive, the lesions are typical of those caused by the avian pox virus (*Poxvirus avium*), a viral infection of birds caused by one of the largest families of viruses of the pox virus group (Marshall and Amidon 2009, p. 6; Wilner 1969, cited in van Riper et al. 2002, p. 929-930).

Avian pox is found worldwide and is able to infect all bird families (van Riper et al. 2002, p. 930). Response to the virus varies among bird families and individual species. There are generally two forms of virus symptoms: skin and diphtheritic. In cutaneous pox, wart-like growths occur around the eyes, beak or any unfeathered skin. This leads to difficulty seeing, breathing, feeding, or perching. In diphtheritic pox, the growths form in the mouth, throat, trachea and lungs resulting in difficulty breathing or swallowing. Birds with either form of pox may appear weak and emaciated (USGS 2013). Avian pox can be fatal, depending on the species' response to the infection. The gravity of threat that avian pox poses to the Tinian monarch should not be discounted, as avian pox is considered to be one of the main threats to forest birds on other islands such as Hawaii (van Riper et al. 2002, p. 930, 939).

Avian poxvirus can be transmitted from mosquitoes, midges, flies, and through contact of infected birds or infected surfaces (van Riper et al., p. 930). An increase in urbanized areas leads to an increase in mosquitoes by creating more breeding grounds in reservoirs, standing water, and abandoned machinery (Marshall and Amidon 2009, p. 7). Domestic birds such as chickens and turkeys provide a source for the disease, and are thought to be the main source of the introduction of pox to Hawaiian forest birds (Marshall and Amidon 2009, p. 7; van Riper et al. 2002, p. 939). Avian pox, as well as predation from introduced rats to the island, was noted as a possible explanation for the recent decline in the Tinian monarch population (USFWS 2009, p. 237).

In addition to disease, predation currently poses a major threat to the Tinian monarch. The survival rate for the Tinian monarch from 2006-2009, based on early warning plot samples, measured an 82 percent survival rate for male monarchs, and a 64 percent survival rate for females (Marshall and Amidon 2009, p. 4). Females may have a lower survival rate because they are more subject to predation than males since the nests are about two meters off the ground in small trees and shrubs where small, predatory animals such as rats, monitor lizards, and feral cats can access them (USFWS pers. obs. 1996, cited in Marshall and Amidon 2009, p. 4). The low female survival rate is cause for concern.

Predation poses a dire threat to the long-term survival of the Tinian monarch. Alarmingly high population densities have been measured for some invasive predators on the island of Tinian. Invasive species are a threat to global biodiversity, but can be even more harmful to island species because of their small geographic range and population sizes, low fecundity, lack of coevolution with invading species, and extensively altered habitats (reviewed in Wiles et al. 2003).

Introduced *Rattus* species and other small mammals often have detrimental effects on native island species and ecology (Wiewel et al. 2009, p. 205). Surveys for the prevalence of these mammals on Tinian were conducted from 2005-2007 (Wiewel et al. 2009, p. 207). The roof rat (*R. rattus*) was found to occur at densities of 185/ac (75/ha) in native forest and the musk shrew (*S. murinus*) existed in densities of 183/ac (74/ha) in tangantangan habitat (Wiewel et al. 2009, cited in USFWS 2009, p. 245; Department of the Navy 2010, 3: 10-6). Estimates of rat densities were found to be higher than on any other tropical Pacific island, and 2-3 times higher than the densities ever found on Guam (Wiewel et al. 2009, p. 214). These high-density populations present a high threat to the Tinian monarch population not only through predation, but also through dietary competition for similar prey that is needed for nestlings (Wiewel et al. 2009, p. 217).

The threat of the establishment of the brown tree snake (BTS) on Tinian presents another great concern for maintaining Tinian monarch populations. The BTS was accidentally introduced to the island of Guam after WWII when there was a heavy amount of air and ship traffic to support military activities (Fritts and Rodda 1998, p. 10; Wiles et al. 2003, p. 1351). The BTS spread from the south to the north of Guam at about 1.6 km/yr, and was well established on the island by between 1968 and 1970 (Wiles et al. 2003, p. 1352). By the 1980s, the BTS had extirpated 8 of Guam's 11 native bird species, and at the snake's peak eruption, they outnumbered birds four to one (Fritts and Rodda 1998, p. 11 Wiles et al. 2003, p. 1352).

In 1993 the U.S. Department of Agriculture and Wildlife Services created a program to reduce the spread of BTS through shipping (Engeman et al. 2002, p. 102). The plan includes buffer zones that have low snake populations to be used as shipping areas, cargo staging areas that have had snakes removed the night before, and trapping efforts to reduce the number of snakes on the island. Most cargo shipped from Guam, however, comes from areas without snake removal efforts, and all of the efforts are compromised after typhoons, which occur often (Engeman et al. 2002, p. 102). When there is a typhoon, the only way to reduce the risk of shipping BTS is to rely on detecting them in the cargo with dogs. In 1998 and 1999, the effectiveness of detector dogs was tested and the dogs had a 61 percent success rate in 1998 and a 64 percent success rate in 1999. The low rates of success were due to both handler and dog errors (Engeman et al. 2002, p. 103).

From 1993 to 1996, 80 percent of the cargo from Guam found to have snakes in it was headed for other Pacific islands (Engeman et al. 2002, p. 102). BTS have been found in Kwajalei, Pohnpei, Oahu, Diego Garcia, Spain, Alaska, Texas, Oklahoma, Rota, Saipan, and Tinian despite all of the efforts to reduce the risk of spread. There have been eight unconfirmed sightings on Tinian, and there have been 75 confirmed reports of BTS throughout the CNMI (Department of the Navy 2010, 3: 10-6). The threat of BTS establishment is high, especially with recently escalated military activities on Tinian. Under the chosen alternative (Alternative 1, see "Military Land Use" discussed in habitat loss section above), there will be increased transport between Guam and Tinian including a proposed 200-400 marines coming to Tinian via air transport from Guam once a month, accompanied by military equipment shipments by barge from Guam once a week (Department of the Navy 2010, 3: 2-14). If the BTS were to become established on Tinian, the large populations of rats and other small invasive mammals would help the snakes spread faster by providing a prey base, even as native species decline or are extirpated. They would also be harder to trap because mice and rats are used as attractants to traps, but if they exist in abundance in the forest, it is less likely that a snake will be lured to a trap (Wiewel et al. 2009, p. 218).

Monarch population declines of at least 30 to 49 percent are projected in the likely event of the brown treesnake becoming established on Tinian (BirdLife International 2013).

The monarch is also threatened by predation from domestic and feral cats (CNMI Division of Fish and Wildlife undated, p. 1; FWS 2005, p. 21). The domestic cat is one of the most damaging species introduced to islands, and is a primary extinction driver for at least 33 insular endemic vertebrates (Nogales et al. 2013, p. 804).

The monarch warrants protection under the Endangered Species Act due to threats from predation and disease.

D. The inadequacy of existing regulatory mechanisms.

Currently, there are no existing regulatory mechanisms that adequately protect the Tinian monarch and its habitat. The monarch was federally delisted in 2004 (69 FR 56367), and it was delisted from CNMI's list of threatened and endangered species in 2009 (Department of the Navy 2010, 3: 10-4).

The Post Delisting Monitoring Plan for the monarch has now expired. Although the final summary of the results of the monitoring was scheduled to be completed in 2010, a report has not been published.

Public Law 2-51 prohibits the direct take, killing, or harassment of forest birds, but offers no protection for the monarch's habitat (USFWS 1999, p. 8536). Conservation areas on Tinian have no "take" policies (CNMI SWARS Council 2010, p. 17).

The Tinian monarch warrants protection under the Endangered Species Act because existing regulatory mechanisms are inadequate to prevent the bird from becoming threatened in the foreseeable future due to numerous ongoing and proposed threats to its remaining habitat as well as unabated threats from other factors.

E. Other natural or manmade factors affecting the continued existence of the species.

I. Noise Pollution

Numerous projects threaten to harass monarchs with noise pollution, chief among them the proposed increase in military activities on the island (Department of the Navy 2010). In addition to the direct impacts on habitat that the proposed activities would have, the quality of remaining habitat will be degraded by noise pollution. Noise and activity from construction is assumed to impact a 328-ft (100-m) wide zone surrounding the perimeter of the range footprint areas for all alternatives (Department of the Navy 2010, 3: 10-16, 10-28, 10-34). The peak noise exceeded by 15 percent of firing events during combat training is 104 decibels (dB), which will reach and impact 577 ac. of forest, including at least 25 ac. of the limestone forest that is prime habitat for the monarch. Sixty-five dB of a-weighted day-night level of noise will be audible in 1,229 ac. which includes 41 ac. of limestone forest (Department of the Navy 2010, 3:10-19). The Tinian monarch's specific stress response to noise is unknown, but the surrounding forests of the proposed training areas are highly important habitats. The monarch uses vocalizations to communicate (BirdLife International 2013), and if they are unable to alter their calls to adjust to the additional noise interference, they might abandon the area, have lower reproductive success, or be unable to avoid predation. The negative effects of noise pollution on forest birds that rely on acoustic signals for communication are well established in the scientific literature (e.g. Bayne et al. 2008, Francis et al. 2009).

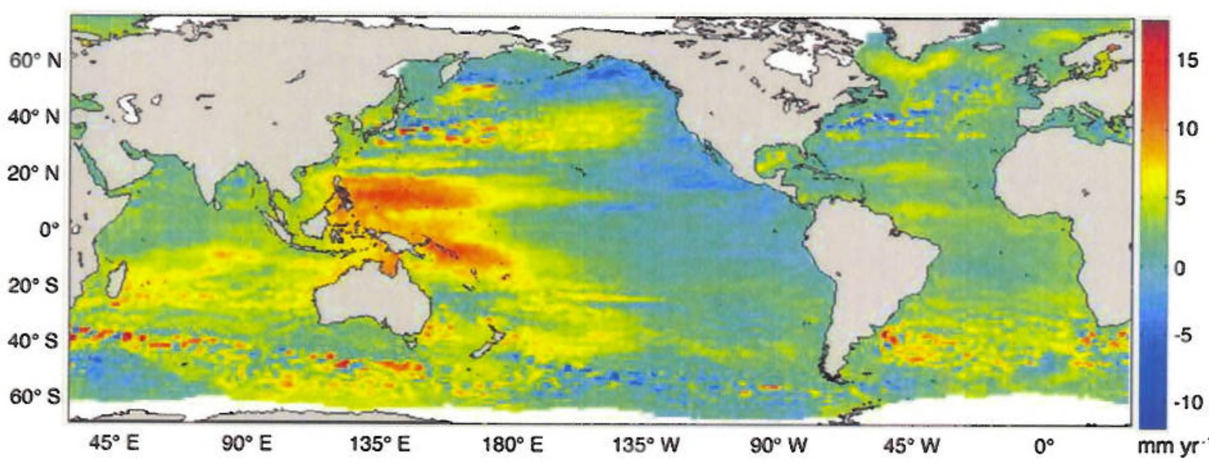
II. Climate Change

Global climate change threatens the Tinian monarch via numerous mechanisms. The effects of global climate change will impact species worldwide and is predicted to cause rapid species-level extinctions (Thomas et al. 2004, cited in Maschinski et al. 2010, p. 148). Island species may be especially at risk due to the inability to relocate and the risks associated with already limited populations (Pimm 1991 cited in Manne et al. 1999, p. 258; Frankham 1997; Ross et al. 2009; Maschinski et al. 2010, p. 148, 153).

From 1993 to 2011, the global sea level rose at an average rate of 3.2 ± 0.5 mm per year, with the highest rise occurring in Micronesia, at Mariana Islands, in Papua New Guinea Islands, and Solomon Islands (see Figure 7) (PIRCA 2012, p. 71; Becker et al. 2012, p. 91). This rate of rise was 60 percent faster than what was predicted by the Intergovernmental Panel for Climate Change (IPCC) (Rahmstorf et al. 2012).

Projections for global sea level rise by 2100 range from 0.5 to 2 m (Rahmstorf 2007, p. 368; Vermeer and Rahmstorf 2009, p. 4; Pfeffer et al. 2008, p. 1342; Grinsted et al. 2008) and are a concern for all island regions (PIRCA 2012, p. 66). Even under best case scenarios, 21 eco-regions, including and especially ones in Southeast Asia, are predicted to lose more than 50 percent of their land area (Menon et al. 2010, p. 8). The total sea level rise trend on Guam (the closest studied island to Tinian) is about 1.8 mm/year since 1950 (Becker et al. 2012, p. 97).

Figure 7: Sea-level trend for 1993–2010 from Aviso altimeter product, produced by Ssalto/Duacs with support from the Centre National d'Etudes Spatiales. (PIRCA 2012, p. 71)



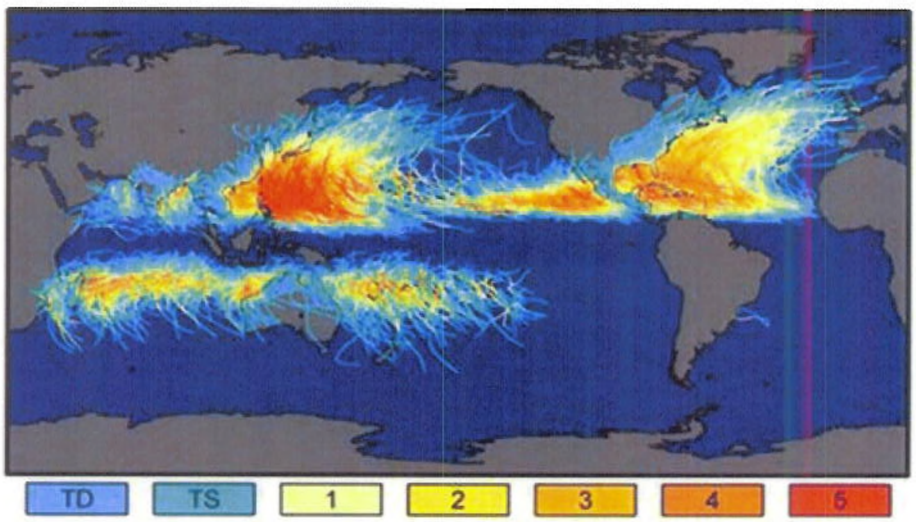
Tinian is threatened not only by rising sea levels but also by increased storm surges. Models show that an increase in sea surface temperature, like what has already been recorded and what is predicted to continue, will most likely lead to more intense storms that will exacerbate storm surge flooding on islands (reviewed in Maschinski et al. 2010, p. 148). Knutsen and Tuleya

(2004, 2008) estimated an average eight percent increase in hurricane intensity for every 1 degree Celsius of sea surface temperature rise (cited in Mousavi et al. 2009). Knutsen et al. (2010, p. 33) predicted an increase in average maximum wind speed of 2-11 percent and a 20 percent increase in global rainfall rates.

Wave runup, the process of waves surging against beaches and structures and causing or promoting erosion, also threatens Tinian. Wave runup represents the most dominant non-tidal sea-level deviation, and could be the largest cause for coastal inundation. Wave-driven inundation is a major concern for the Pacific Islands region (PIRCA 2012, p. 82).

Trends in extreme levels of surging tend to follow trends in mean sea level (PIRCA 2012, p. 82). Tinian is particularly vulnerable to increased surging because it is located in what is referred to as Typhoon Alley (Figure 8) which puts it at risk for frequent and energetic storms (DOI 2006; PIRCA 2012, p. 73). Typhoon Keith, for example, caused extensive damage when it swept through south of Tinian in 1997 and illustrates the swift and dramatic changes that can occur on islands (BirdLife International 2013).

Figure 8: Tracks and intensity of all tropical storms. Saffir-Simpson Hurricane Intensity Scale (PIRCA 2012, p. 74)



The monarch's habitat is threatened by damage from storms and sea level rise and also by displacement of people into the island's interior due to these factors (CNMI SWARS Council 2010, p. 31). San Jose, Tinian's most populated town, sits on the coast at approximately zero ft of elevation. Coastal inundation caused by more intense storm surges coupled with a higher sea level is already driving the re-location of many residents on some Pacific islands such as Fiji, Western Samoa, Tonga, etc. (Nunn and Mimura 1997, cited in Fitzgerald et al. 2008).

Climate change could also threaten the monarch and its habitat via other factors such as changes in forest composition and spread of invasive species (CNMI SWARS Council 2010, p. 31).

III. Restricted Range

Populations restricted to small islands are naturally more vulnerable to threats such as invasive predators, diseases, and climate change because of their limited ability to leave and recolonize elsewhere and because of their naturally lower genetic variation (Pimm 1991 cited in Manne et al. 1999, p. 258; Frankham 1997). In a study done by Frankham (1997), island populations were found to have lower genetic variation than mainland populations, and island endemics were found to have even lower genetic variation than non-endemics (p. 320). Limited ability to adapt to environmental change, low genetic variation, inbreeding depression, accumulation of deleterious mutations, and genetic adaptations to island environments can all place island species at higher risk of extinction (Carlquist 1974; Myers1979; Soulé 1983; Temple 1986; Vitousek1988; Atkinson 1989; World Conservation Monitoring Centre 1992 cited in Frankham 1997, p. 321). Even island species with relatively large population sizes compared to their available habitat may need federal protection earlier in the stages of decline than what may be considered necessary for continental species. Since the 1600s, 97 out of 108 known bird extinctions have been on islands (Johnson and Stattersfield 1990, cited in Manne et al. 1991, p. 258). The Tinian monarch only exists on Tinian, which is a small 24,960 acre island with very little forested habitat remaining (Duenas, Camacho & Associates, Inc. 2012, p. 4-12). Given the monarch's limited range, declining status, and multiple habitat threats, the flycatcher needs federal protection to ensure its survival.

CONCLUSION

The Endangered Species Act requires that the Service promptly issue an initial finding as to whether this petition "presents substantial scientific or commercial information indicating that the petitioned action may be warranted." 16 U.S.C. § 1533(b)(3)(A). According to the best available science, there is no question that under the five listing factors of the Act, protecting the Tinian monarch as threatened or endangered may be warranted. The monarch has experienced significant population decline since 1982, and is threatened by loss and curtailment of habitat or range, disease and predation, and various other factors including climate change. Protections made for the Tinian monarch could also provide other native species with benefits as well, especially those who also suffer from predation by rats, loss of forest habitat, and birds who are susceptible to avian poxvirus.

There are no existing regulatory mechanisms that are adequate to protect the monarch, and in order to stop its present decline, preserve its remaining habitat, and allow for recovery, it should be promptly protected under the Act.

On behalf of all parties,

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memorandum

date September 30, 2015

to The Honorable Eloy Inos, Governor
Commonwealth of the Mariana Islands

from Jim Keany, Biological Resources Director
Environmental Science Associates, Seattle, WA Office

subject Comments on Navy Draft CJMT EIS/OEIS

At the request of the Governor's Office of the Commonwealth of the Northern Marianas Islands (CNMI) Environmental Science Associates (ESA) reviewed the Navy's CJMT Environmental Impact Statement (EIS) and assessed the analysis for adherence to accepted scientific and National Environmental Policy Act (NEPA) practices. The reviewers for this effort represent senior staff within ESA with over 180 years of combined technical and NEPA experience. These staff include:

Name	**Degree**	**Professional Experience**	**Role**
Jim Keany	M.S. Wildlife Ecology	33 years	PM and lead scientist for review
Ann Root	Ph.D. Geography/Water Resources,	25 years	NEPA
Bob Sullivan	B.S. Fisheries Science	30 years	Fisheries/Marine Resources
Sharese Graham	B.A. Marine Biology	15 years	NEPA, Marine Resources, Planning Elements
Eric Schniewind	B.S. Geological Science	20 years	Ground and surface water
Chris Lockwood	Ph.D. Anthropology	18 years	Cultural and historic resources
Mike Arnold	B.S. Civil Engineering	25 years	Noise and Airspace
Susumu Shirayama	B.S. Aerospace Studies	15 years	Noise and Airspace

Introduction

The President's Council of Environmental Quality (CEQ) has promulgated mandatory regulations and guidance for NEPA document preparers. Over the years these materials have stressed that NEPA documents must be developed in good faith, provide full public disclosure, and follow sound science, engineering, and policy analysis practices. The ESA team used these CEQ materials as well as their accumulated experience in NEPA and their technical fields in reviewing the Navy CJMT EIS. The results of this review are discussed below by major topic area. Some examples are provided under each heading, but many of these issues are prevalent throughout the EIS and within all subject matter headings.

Lack of Island Biogeography Context

The total land mass of the CNMI is about 17% of the size of Rhode Island. In addition, the island of FDM is currently used as a bombing range and is uninhabitable for wildlife in most areas, therefore reducing the amount of potentially viable habitat in the CNMI. Effects to rare species from the Navy's proposal would be particularly devastating for rare and endemic species found only on the islands of Tinian and Pagan. For example, the Tinian monarch (or Tinian flycatcher) is only found on the island of Tinian – nowhere else in the world. The preferred alternative would remove over 9% of its habitat, making it more susceptible to the continued disturbance of military training, natural population fluctuations, and extreme events such as typhoons. A prime example of this natural disturbance interval regime is the major typhoon that devastated the CNMI on August 2, 2015. Early reports indicate substantial damage on Saipan and Tinian – including widespread wind damage affecting the Tinian monarch suitable habitat. A University of Hawai'i study (Camp et al. 2012) notes the vulnerability of the Tinian monarch to habitat disturbances from typhoons and from the proposed Navy training.

The CJMT EIS does not acknowledge the special context of island ecology and lacks a science-based analysis. The EIS consistently uses acres of habitat loss as an index of magnitude of effects to habitat and wildlife. While loss of 100 acres of habitat would have relatively minor effects to common wildlife on the mainland U.S. – loss of the same area of habitat on a small island that supports endemic and rare species has vastly different consequences. **The effects conclusions in the EIS do not account for the special nature of island ecology, the unique geography of the CNMI, and are consistently arbitrary and speculative.**

Because of their small size and isolation, the islands of Pagan and Tinian are home to a range of endemic, rare, and endangered species that are particularly vulnerable to disturbances. The small populations of rare species on oceanic islands, restricted ranges, and limited diversity of defenses make island biotas particularly vulnerable to extinction through habitat loss or introduction of invasive species (Paulay, 1994). Applicable to Tinian and Pagan Islands is the severe threat of introducing the brown tree snake from Guam, where it has decimated the native bird populations. A thorough risk analysis has not been performed for this likely outcome and the Navy refers to a Biosecurity Plan that they will develop as some later point. No details are provided and one cannot evaluate the adequacy of the "program." Other studies that have reviewed the vulnerability of pacific islands (Carew-Reid, 1990) found that the natural environments of the South Pacific islands are degrading rapidly, and suffer some of the highest rates of species extinction in the world. Further, these islands support some of the highest proportions of endangered species per unit land-area. Island populations are more prone to extinction than mainland populations, particularly rare and island endemic species having highest extinction rates (Frankham, 1998).

In the effects discussion for two endangered bird species, as an example, the Micronesian Megapode and the Micronesian Common Moorhen, the EIS addresses potential disturbance by referencing several studies for species such as woodpeckers on the east coast of the U.S. mainland. **The effects analysis ignores the specific vulnerability of these island species, uses non-applicable examples that do not reflect the limited habitat and disturbance regime of an island ecology landscape, and ignores the long-term habitat degradation and disturbance effects from the proposed large-scale training and naval exercises**.

The EIS includes no science-based assessment of how the proposed training will affect the current small populations of rare birds and bats. There is no analysis of ultimate factors – habitat loss, threat of invasive species, noise and human disturbance – or proximate factors such as stochastic population mechanisms – which are all severe threats to species on small oceanic islands (Spielman et al 2004). These threats can interact through different processes to cause extinction (Hedrick, et al 1996). These are important ecological processes on oceanic islands not considered in the EIS. Assessing the viable population size for island rare species includes a complex consideration of demographics, natural disturbance regimes, habitat availability and human disturbance factors, and genetics. These are ignored in the Navy CJMT analysis for rare species – which includes a number of bird species, the Mariana fruit bat, reptiles, and a number of terrestrial invertebrates and marine invertebrates.

The discussion in the EIS of the effects of the Navy proposal to island biodiversity is deficient, lacks any scientific credence and was developed as if the project were located at a generic mainland U.S. location and not on a very unique and vulnerable South Pacific island landscape. The discussion of the range of effects to wildlife on Tinian and Pagan needs to be completely revised and should be developed based on a sound scientific foundation of island landscape ecology principals and using an analysis framework applicable to the South Pacific.

Lack of Baseline Data

To make a valid assessment of the effects of any project, a baseline must be developed against which project effects are measured. Even where it is challenging to develop a baseline for all resources, an EIS needs to demonstrate a sufficient effort in using existing reports, using local knowledge and expertise obtained by coordinating with agency resource professionals, and conducting field data collection in a manner that corresponds to the level of potential effects to resources. When the range of potential effects is more variable and less certain, or potential effects may be significant, then a greater effort is needed to develop a baseline to inform the analysis.

For many resource areas and actions within this EIS this basic premise is ignored. Local resource agencies have the most knowledge of the project area concerning habitat, wildlife, rare species, cultural resources, groundwater, etc. Typically, a first step in developing baseline data is to work closely with natural resource agency staff in identifying the key existing data sets, the data gaps, and the studies needed to adequately address these data gaps. None of these steps were followed in preparing this EIS. **Instead it appears that the Navy relied on a subset of the reports that were readily available to them – leaving out a number of other reports and data sources held by (and available from)**

resource agencies. In addition, insufficient effort was made to collect baseline data. Some examples of this include:

- Out of date aerial photographs of Tinian and Pagan were used when obtaining new ones would have required minimal effort and provided more accurate information on existing conditions.
- Extremely limited wildlife and plant surveys were conducted on Pagan without contacting the CNMI Division of Fish and Wildlife, which could offer explicit information on needed data collection.
- No data collection was conducted on existing soil and groundwater contamination on Tinian from World War II era munitions and mortar range.
- There is a complete lack of baseline data for seabirds that will be affected by the proposed project.
- Wetlands extent and ecological function data for Tinian and Pagan Islands is incomplete and inaccurate for the Hagoi, Bateha, and Mahalang sites on Tinian.
- Endemic arthropod species on Pagan and several arthropod species that are new to science recently discovered on Pagan are not mentioned (Evenhuis et al, 2010).
- No attempt was made to assess the baseline condition for marine mammals.
- There is no baseline data for the endangered Mariana Fruit Bat.
- Extremely limited cultural resource surveys were conducted and no analysis was completed on the applicability of cited past surveys to the proposed land disturbing activities.

These are a few limited examples, but illustrate what is a pervasive problem noted throughout the document. Each resource area needs to be fully evaluated, the Navy should coordinate with local agencies regarding data needs and local expertise, and additional baseline data needs to be collected for most resource areas to comply with NEPA requirements and standard analysis practices.

Cultural Resources

In addition to archaeological resources, architectural/built resources, and Traditional Cultural Properties, the CJMT EIS repeatedly references "other" cultural resources significant in the present-day and provides examples including "cultural practices, cemeteries, memorials, sacred sites, medicinal plants, or other resources that hold special traditional, religious, or cultural significance." The list is in no way comprehensive or even necessarily culturally-specific, and it is entirely unclear whether this flawed inventory was compiled using any direct input whatsoever from representatives of the islands' traditional and ethnic communities. The glaring omissions of fish and cattle, among others, from the list of culturally-important resources underscore its fundamental flaws. Given the paucity of resources listed as culturally-important, it comes as little surprise that the CJMT EIS repeatedly fails to identify culturally-important resources within areas of impact and finds "No resources of cultural importance."

The CJMT EIS makes claims directly contradicted elsewhere in the document. For example, in 3.11.5.1 the EIS indicates that surveyed areas of Pagan are in the center of the island and "are not located near coastlines where most sites tend to be found." However, this claim appears to be contradicted: "Most of the [cultural resource] sites are located in the relatively flat areas in central Pagan, south of the Mount Pagan caldera." At other times, the CJMT simply makes unsupported assertions. For example, in 4.11.2.2, it is asserted that "[s]hould sites be preserved under the lava, impacts are unlikely since the depth of the ground disturbance associated with munitions would be less than the depth of the lava." No data or studies assessing the resistance of lava to munitions, including the long-term and cumulative impact of high-explosive bombs, are cited to support this claim.

The CJMT EIS relies quite heavily upon existing archival resources both to document the presence of historic and cultural resources, and to demonstrate the spatial extent of previous cultural resources research. The referenced studies were conducted over a period over nearly 60 years by different researchers using a wide array of methods. At no point does the EIS explain the relevance of these studies, their methods or results, to the CJMT undertaking and its specific impacts. Because the CJMT undertaking will necessarily result in different impacts (e.g., depth and extent of ground disturbance) than the undertakings for which the existing studies were conducted, it is incumbent upon the CJMT EIS to demonstrate that approaches and methods used during previous studies are, in fact, relevant to the full range of impacts expected from the current undertaking. Far from providing a cogent discussion of methods used during previous studies, the CJMT EIS presents inconsistent nomenclature regarding simply the types of investigations that have been conducted. Only approximately 33% of the island of Pagan has been subject to cultural resources surveys. The lack of survey coverage allows that far more cultural resources exist than have been recorded; thus it is quite premature for the CJMT to draw conclusions that no significant impacts exist or that significant impacts can be mitigated to less than significant.

Research completed specifically for the CJMT undertaking consists of one supplemental archaeological assessment and one traditional cultural property study for each of Tinian and Pagan. It is very problematic that the redacted traditional cultural resources studies provide no explanation of methods used to select the small number of ethnographic participants involved, the questions asked, or any critical review of results in terms of completeness of TCP inventory. The TCP studies were conducted over a short time frame, suggesting there is not likely to been time to develop the sorts of durable and trusting relationships between ethnographer and participants required to elicit accurate, culturally-sensitive information. The CJMT EIS fails to admit that members of traditional and ethnic cultures may deliberately choose not to divulge the location, extent, activities performed within, or beliefs regarding landscape areas that might otherwise be recognized as traditional cultural properties. Furthermore, this definition fails to acknowledge that a "community" is composed of individuals, who possess a multitude of cultural identities and experiences, and therefore may assign different beliefs and values to the landscape.

Furthermore, the CJMT EIS makes no substantive effort to use existing archaeological, geologic and other environmental data sets to understand the potential for undiscovered and undocumented cultural resources. Predictive modeling using environmental and cultural parameters is a routine, even basic approach in cultural resources management. In the few instances where specific environmental factors are considered, they are used to identify settings where cultural resources *were assumed to not be expected* – beneath lava flows and along steep slopes, for example – rather than to evaluate the differential cultural resources potential for the entire landscape. And, even some of these assertions appear to be contradicted within the EIS itself. For example, the EIS suggests areas with topography with slopes greater than 30% "are unlikely to contain historic properties," and nevertheless asserts "Japanese military sites are found *in cliff sides* [emphasis added] and on top of high points overlooking beaches." The potential for undocumented cultural resources on Tinian and particularly Pagan Islands is high and deserves additional site survey and use of predictive modeling.

Noise

The first paragraph of 5.1.2 describes the baseline noise contributions of current training that occurs at North Field. It states that "These activities are infrequent and do not generate perceptible noise levels for populated areas to the south in San Jose or to the north in Saipan". **There is no source for this claim nor is any data provided**. During public meetings a large group of Tinian residents discussed the noise disturbance from the current training including having to close the public schools for several days and residents applying for compensation to the Navy for broken windows due to noise. In addition, the Navy recently compensated a rancher for loss of his goat herd on Tinian due to loud plane noise during the North Field training exercises. It is not clear how the conclusion presented in the Appendix was generated – but it appears to be a false assumption.

Additionally it is not clear what criteria is used to reach this assumption – is this paragraph based on Average Annual Day (ADD) operations? If yes, Average Busy Day (ABD) needs to be reviewed and analyzed. Please refer to analysis guidance in OPNAVINST 11010.36C Chapter 3, 2a.

The description of the affected environment lacks the data to substantiate the baseline conditions. **The CJMT DEIS states that the noise metrics described in Section 3.5.1.3 were used for the affected environment; however, it does not appear that there were any noise measurements taken on Tinian, Saipan, or Pagan to define the current noise environmen**t.

Local residents report that during the last North Field training exercises, the local schools had to be closed due to the disruptive nature of the noise generated by the training. **It does not appear that any measurements were taken to verify that the current military training activities fall within the reported peak sound levels, or that the sound levels outside of the Military Lease Area remained below the threshold. The determination that the existing training noise is imperceptible outside of the Military Lease Area boundaries is an assumption with no data to provide verification**.

While the DEIS states that it is not possible to model infrequent events, such as those that occur at the North Field, *Army Regulation 200-1 Environmental Protection and Enhancement*, which Appendix H Noise cites as the guiding analysis document, provides guidance for such events that the Navy has chosen to ignore. Specifically:

14-4a(2). *Supplemental metrics, such as single event noise data (for example, Peak, PK 15(met) or CSEL), may be employed where appropriate to provide additional information on the effects of noise from tests and training ranges.*

Thus, the Navy has options on how to deal with these irregular events. In addition, the Navy has compensated Tinian residents (as expressed in public meetings) in the past for infrastructure damage from noise – such as broken windows, due to North Field operations. The Navy does not provide any baseline account of these actions although Army Regulation 200-1 clearly notes the requirement for recording such incidents:

14-1d. *Monitor, record, archive and address operational noise complaints.*

Clearly indicating the baseline conditions, *including* the current training regime effects, is needed for a full evaluation as required by NEPA.

Lack of Clear Significance Thresholds

A key part of the NEPA analysis is determining if a particular action will have a "significant" effect on a specific resource. While NEPA does not try to define what significance means for every possible project type, CEQ regulations require that an analysis include the context and intensity of a given effect vector. In addition, the sensitivity of a specific resource is a key factor for consideration. For instance, effects of vegetation loss would be less important for a very common wildlife species on the mainland, but potentially significant for a rare species on an island.

In the Navy CJMT EIS, most of the resource area analysis includes a vague set of significance thresholds that provides no standardization of the analysis and does not support the EIS conclusions. Conclusions appear based on no presentation of factual information, logical analysis, or discussion of outcomes. **In many cases there is no discussion at the beginning of a section as to what would constitute a significant effect, yet the EIS authors repeatedly come to the conclusion that the project actions will have a less than significant effect**.

A prime example of this is in the Water Resources section. The subsection titled "Approach to Analysis" is one sentence long*: The analysis considers information from the technical studies and surveys conducted for the CJMT EIS/OEIS and factors and conditions that can potentially affect water resources.* Subsections on Surface and Groundwater go on to list activities that can "possibly" affect these resources, but there is no discussion of what would constitute a significant impact, what is the baseline used for analysis, and how munitions interact with soil and groundwater. Yet the analysis is full of conclusory statements such as: *Tinian Alternative 1 operations would result in less than significant direct and indirect impacts to groundwater resources.*

Similarly the discussion in the Vegetation section makes a rhetorical leap and provides a vague description of what might be considered a significant effect – referring to "high, medium, and low" impacts, yet without providing any definition of these terms. There is no description of what constitutes a "significant" impact. Interestingly, the Navy, in a previous document (*Guam and CNMI Relocation EIS*, 2010), notes that a terrestrial impact would be considered significant if there were ANY loss of native limestone forest: "*Any loss of this forest vegetation community would be considered significant because of the large historical and continuing losses of this forest type on Tinian. Loss of wetland or mangrove vegetation would also be considered potentially significant.*"

In the current CNMI EIS/OEIS the Navy appears to change its mind and presents a vague set of significance thresholds with no clear quantification or standardization – only vague references to undefined small, medium, or large effects taking into account the relative rarity of a vegetation community. In the CJMT EIS, the Navy uses a vague and arbitrary definition of impacts. Therefore, the conclusions are unsupported.

Without a structure for defining a significant impact, statements about the degree of impact are meaningless and do not comply with NEPA regulations and standard environmental analysis practices.

The Navy should develop supplemental information that includes significant thresholds for each resource area and then analyze the project's effects using these metrics.

Substandard Analysis of Potential Effects

In reviewing the EIS, it is obvious that a lack of meaningful analysis of potential effects is a common problem for all resource areas. NEPA regulations and standard practices for an environmental review process require effects analysis of a project to use metrics of intensity, duration, frequency and context (CEQ Regulations). These must be assessed against the baseline existing conditions and inferences should be made based on published studies of similar situations and/or common policy or regulatory standards. The narrative should follow a logical, step-wise approach that allows the reader to easily understand how the analyst was able to draw such conclusions.

These standard practices are consistently ignored throughout the Navy CJMT EIS. **One is often left wondering how a conclusion was reached without a thorough analysis of potential effects, a lack of links to applicable studies or literature, a lack of a description of the analysis framework used, and conclusions that appear to be developed without regard to project intensity, duration, frequency or context**. The effects analysis throughout the document does not comply with NEPA regulations or standard environmental analysis practices.

For instance, the EIS concludes that live fire training and other activities will not have significant effects to the Micronesian Megapode, a rare forest bird species, partly because the animal has low densities on Tinian. Because the species is rare is not a reason for determining the level of effects. Rather, standard environmental practices would consider this species' productivity and long-term survival more susceptible to the effects of noise and human disturbance because its population numbers are so low and therefore at risk. In addition, there is a wealth of data to draw upon in the scientific literature that describes the long-term effects of continual disturbance to survival and productivity of ground-nesting birds. Yet this section of the EIS, and many others, cites no literature to support conclusions that there will be no significant effects to this species. The Navy should review all resource sections and clearly articulate a framework for analysis for each section, follow this analysis, and revisit conclusions.

The CJMT EIS provides little to no detail regarding specific methods of cultural resource data analysis and how conclusions were drawn from these data. For example, the EIS indicates "The Tinian and Pagan RTAs and their associated support facilities/infrastructure construction footprints were examined in relation to locations of historic properties and resources of cultural importance using Geographic Information Systems to identify potential impacts due to construction and operations." However, Geographic Information Systems is a suite of interrelated and open-ended spatial, statistical and other analytical tools. No explanation of what kinds of analyses were performed to understand potential impacts is provided. Elsewhere, the CJMT EIS notes that aerial survey was performed for archaeological sites on Pagan. Given the presence of widespread, often dense, vegetative cover it is simply implausible that aerial survey could reliably identify anything but the largest, densest and most obvious cultural resources.

Noise Analysis

The DEIS, in Section 4.5.1, clearly states that the results of studies “conducted to examine the effects of military noise exposure, focusing primarily on stress response, blood pressure, birth weight, mortality rates, and cardiovascular health” are inconclusive. A correlation between these indirect noise effects and military noise exposure cannot be proved or disproved; therefore, they should not be discounted.

Section 4.5.1.1.2 of the DEIS discusses the noise generated by underwater construction activities at Unai Chulu. Pile and sheet pile driving are reported to generate noise levels up to 177 decibels referenced to 1 micro Pascal root mean squared, with a reduction of 25-30 decibels if vibratory methods are used. The DEIS discounts potential impacts to humans from pile or sheet pile driving due to an established perimeter for recreational divers. The DEIS does not give the distance of the perimeter or the anticipated noise level at or beyond the perimeter. The DEIS does not discuss the noise from pile or sheet pile driving as heard by receivers on land. The DEIS does not give any data to support the conclusion of less than significant impacts to humans from construction noise.

The DEIS (page 4-450) concludes that there would be no significant noise impacts from training because only residents of 10 houses would be affected and they make up only 1 percent of the population of Tinian. There is no justification for less than 1 percent of the population as the significance threshold. The DEIS also appears to assume that residents will simply stay put in their houses and not move about the island as they typically do. There are no resident use studies to indicate how the island is used by residents, who typically travel around the island to visit family, tend to livestock, gather plants, or fish. Similarly, during North Field training in 2014 the Tinian public schools closed for several days because the noise severely affected teaching and student comfort. There is no accounting for these past disruptions or how the very quiet existing conditions will be affected from this massive training proposal. The population would be significantly impacted because of the very low noise levels to which they are accustomed on both Tinian and Pagan. These noise impacts should be identified as significant and mitigation should be provided.

In general, the noise analysis in the DEIS bases the significance determination on equivalent noise levels. As discussed above, the existing noise environment on Tinian and Pagan are not typical of the zoning categories provided in these rating systems. The additional noise from operation of the project would constitute a perceptible change in the noise environment, regardless of the equivalent noise level measured. **The noise analysis should also evaluate the *change* in noise levels, similar to the FAA significance threshold of a 1.5-decibel increase in noise sensitive areas over 65 decibels (Section 4.5.1.2.2).**

The DEIS does not evaluate the vibration effects from construction or operation of the project. A vibration analysis should be included in the DEIS.

Section 5.1 of Appendix H – Noise Study states that the “current noise environment on Tinian is typical of a small rural town or suburban area.” Tinian is a small island village, which does not fit into that category for typical noise generation. Tinian lacks any noise-generating development or infrastructure other than the airport. Although the DEIS is not incorrect in placing Tinian and Pagan into the Zone 1 category, for existing ambient noise levels of <65 decibels A-weighted, the existing land uses are not typical of those found within the contiguous U.S.

In Section 5.1.1 the analysis states that "Sound dissipates at the rate of 6 decibels per doubling of the distance from the source" yet the earlier statement of "The small-caliber weapons firing produces Peak noise levels of 90 to 100 decibels at 500 feet (152 meters) and 80 to 90 decibels at 1,000 feet (305 meters) for the…." – indicates a decrease of 10 decibels with doubling of the distance. The analysis is incorrect.

It is not clear how the noise contours for Figure 5.1.2 were generated. Are these from a previous study? If not, are they from a study generated for this project? Also, there is no mention of INM in this report. Since the majority of the aircraft operated at this airport are civilian aircraft, NOISEMAP (model used) is not suitable software to use for this effort. Another possibility is that these contours represent only military aircraft, but this is not clear. Please revise accordingly and to accepted analysis standards.

Section 6.1.1 (3rd paragraph) notes that noise levels from construction would be "…82 decibels at 100 to 500 ft…" from the source. But based on the attenuation rate of 6 dB per doubling the distance, when it is 82 dB at 100 feet the noise will be 46 dB at 6,400 feet and when it is 82 dB at 500 feet, the noise will be 60 dB at 6,400 feet. It is not clear how the analysis ends up with a noise level of 49 dB at the school. In Table 6.2-5 Note 2 indicates that the noise level threshold is 50 dB ADNL. Is this for a specific receiver? This is not clear and needs to be addressed as it makes a large difference in effects, depending on the receptor.

Section 6.2.2 describes a large increase in the area exposed to the 65 dB DNL contour. But it is not clear how this relates to long-term land use plans for the affected areas. Existing and future land use maps should be prepared for the entire island to provide a better understanding of potential noise effects from the various training sources. In addition – no flight track information is provided that shows the track use, density, timing, aircraft types and locations, which should be shown to provide a full understanding of the areas exposed to overflights. It is not possible to validate the assumptions and conclusions of this technical report without such information.

Section 6.2.2.1 (paragraph 2) refers to the "baseline" – but it is not clear if this means under existing conditions (accounting for noise from current training) or to the proposed action conditions. Please clarify.

Section 6.2.3.1 states that "…a 12 to 24 decibel attenuation provided by building with windows opened or closed". In this tropical environment with limited air conditioning in the school, it is likely that windows will be open most of the time. In addition – no evidence is provided for this assumption of large noise attenuation with windows opened or closed. This appears to be an overestimation of such effects. Please use existing literature to provide an acceptable analysis and consideration of how the building actually is used. We suggest coordination with the Tinian Mayor's office for such information; such coordination appears to be lacking.

From the information provided in Section 6.2.3.1 it is not clear what is the threshold for analysis for the number of events greater than 90 decibels. **If aircraft conduct repetitive training operations, such as touch and go, the number of events greater than 90 dB can occur at 5-minute-intervals.** Also relate these potential effects to actual effects experienced by the school (several day closings) due to existing training at North Field**.**

The last sentence in the first paragraph of 6.2.3.1 states “table 6.2-18 presents indoor speech interference under baseline conditions at representative locations” but the table is titled “All Tinian Alternatives Indoor Speech Interference Events at Representative Locations on Tinian”. Revise the text or the table accordingly. No baseline data are provided in Table 6.2-19 to compare with estimates of the proposed action noise events. Baseline conditions should be defined with the 9-hour Leq.

Section 2.2.3 states that FHWA’s traffic model is used. Please describe how it is used for vehicles included in Table 6.2-22. This is not clear.

In the paragraph following Table 6.2-22 it states “this would result in hourly equivalent noise levels of 64, 59, 56, and 54 decibels at 50, 100, 150, and 200 feet from the roadway.” The first paragraph of Page 1-4 states that a passing vehicle attenuates by about 3 decibels for each doubling of distance. Please define the basis of those indicated noise levels and attenuation rates.

Airspace

In 2012, the Tinian International Airport served 49,116 flight operations. The large majority of these (46,206 reference in affected environment or 48,640 referenced in Table 8 of Appendix I) were air taxi operations. Total flight activity averaged 135 operations per day. Assuming those flights are spread throughout roughly 10-12 hours per day would result in a non-peak average of 11-13.5 operations per hour with a peak hour likely approaching 20 operations/hour.

The note in Table 5, Proposed Special Use Airspace Use, of Appendix I indicates “Hours per day are not cumulative as Airspace Units may be activated independent of each other or simultaneously”. If this same consideration applies to annual number days of use, at least one of the many areas of special use airspace could be restricted every day of the year rather than limited to 135 – 140 days as noted in the table.

The relocated flight paths increase the distance flown and also require a south traffic pattern that increases the potential for overflights of populated areas. **Also, the “future” flight routes provided closely skirt the edges of the special use airspace and thus are more likely to need additional buffer space than what is indicated– which translates into a longer flight diversion path**. Given the volume of the air taxi operations, the increase in roundtrip flight time, and the potential that some level of restriction could be in place virtually every day of the year, this raises significant concerns regarding flight scheduling, added fuel cost, difficulties in dealing with weather conditions, and restrictions to local residents, commercial traffic, and tourists.

Appendix I notes that resource impacts will be addressed per FAA Order 1050.1E and Order 505.4B but the DEIS Chapters 3 and 4 make no mention of these guiding documents. The DEIS should be adjusted to include an analysis according to these FAA Orders.

Lack of Mitigation, Misrepresentation of Mitigation

According to the CEQ (40 C.F.R. §1508.20) Mitigation includes the following step-wise progression of actions:

- Avoiding the impact altogether by not taking a certain action.
- Minimizing impacts by limiting the degree or magnitude of the action and its implementation.
- Rectifying the impact by repairing, rehabilitating, or restoring the affected environment.
- Reducing or eliminating the impact over time by preservation and maintenance operations during the life of the action.
- Compensating for the impacts by replacing or providing substitute resources of environments.

Thus, a NEPA document must show that efforts were made to avoid and minimize project effects and when effects are unavoidable, viable and specific mitigation must be developed. This information must provide sufficient detail to indicate how the mitigation will adequately compensate for the described spatial and temporal adverse effects.

The Navy CJMT EIS repeatedly ignores these best practices across all resource areas. **The inadequacies come in several forms – 1) a lack of impact avoidance analysis, 2) erroneous conclusions that mitigation is not necessary or required, 3) reduction of effects to less-than-significant with no specific mitigation offered, and 4) ambiguous and noncommittal mitigation proposals**.

Throughout the document there is only a cursory discussion on how construction or operations were developed to avoid project effects. These issues also extend to the inadequate Alternatives Analysis – because no other sites other than Pagan and Tinian are considered, the effects to resources on these islands are considered a foregone conclusion. The impact avoidance discussions within each of the resources areas are limited to a summary of "Best Management Practices." For instance, for the proposed 10 acre amphibious landing ramp at Unai Chulu on Tinian, the Navy CJMT EIS refers to a "….careful selection process…" used to determine ramp locations and avoid impacts – the reader is then referred to *Appendix J: Amphibious Beach Landing Site Engineering and Coastal Process Analysis.* This report is merely an engineering feasibility and cost analysis that includes some review of construction techniques. It includes no discussion of impact avoidance by reviewing alternate sites or considering optional configurations and does not meet NEPA requirements or standard impact avoidance and minimization analysis practices.

The Navy CJMT EIS also consistently downplays the need for mitigation and repeatedly comes to the conclusion that effects are "less-than-significant" with no factual analysis or documented decision process provided in the document. For instance, the potential effects of construction and live-fire exercises on two endangered bird species – the Micronesian Megapode and the Micronesian Common Moorhen – are dismissed as less-than-significant without any noise or long-term disturbance analysis. Similarly the analysis on the potential effects of decimating the Mariana Fruit Bat population on Pagan lacks any specifics and does not describe the larger island-wide implications of these effects to this federal endangered species. In addition, Mariana Fruit Bats are significantly tied to seed dispersal and plant pollination in this island ecosystem (Cox, et al. 1991) and the EIS does not consider adverse effects to these direct plant ecology links.

NEPA requires that an analyst review relevant literature on noise effects on ground-nesting birds, determine thresholds where effects would occur, determine the noise levels and duration that these species would encounter, and then make an assessment of effects. If adverse effects were identified then changes to construction practices or operations could be made accordingly – or mitigation could be proposed. None of these NEPA requirements or standard practices were followed in the CJMT EIS.

The EIS includes none of these elements yet it makes a logic leap and concludes that effects to these species are minor because these species have "rare occurrences…" and would be expected to "habituate" to noise and continued disturbance. There is a wealth of literature on the disturbance of ground-nesting birds, long-term disturbance, and susceptibility of rare species in an island landscape – the CJMT EIS does not cite scientific literature or offer a logic framework in making this apparently arbitrary conclusion.

Even when mitigation is deemed necessary in the CJMT EIS, no specifics are provided. Most often the Navy states that a "plan" will be developed at some unspecified time in the future. Without a description of specific mitigation measures, it is impossible to evaluate if the mitigation adequately compensates for the anticipated adverse effects. For instance, as part of significant impacts for effects to forest birds including the Tinian Monarch the Navy proposes to prepare a "…Bird Monitoring plan.." and a "…Management Plan." Details are not provided for either. Non-specific references to land that "may" be set aside for habitat conservation leave the reader with nothing of substance to evaluate relative to mitigation.

Even in instances when the Navy refers to where it "may" offer conservation set-aside areas, it appears that they have already offered these sites as mitigation in a previous NEPA document. The *Guam and CNMI Relocation EIS* shows maps of Tinian with two wildlife reserve areas – one titled the FAA Mitigation Area, which is referred to as the Tinian Military Retention Land for Wildlife Conservation in the CNMI EIS/OEIS; and a second area referred to as the No Wildlife Disturbance zone, which does not appear on the existing conditions map of Tinian in the CNMI EIS/OEIS. Interestingly, this No Wildlife Disturbance Zone is displayed in the CJMT EIS on Figure 4.9-2 Potential Mitigation Areas with Implementation of Tinian Alternatives 1, 2, or 3.

So here it appears the Navy is proposing as mitigation, an area that was previously defined under an earlier NEPA document as a No Wildlife Disturbance Zone under the existing conditions. In addition, the previously committed wildlife mitigation area (the former FAA mitigation site) has been removed and replaced by a smaller area that "may" be used as mitigation under this current CJMT EIS. Presenting an area for mitigation (the No Wildlife Disturbance Zone) that has already been set aside for wildlife under a previous NEPA document is confusing, misleading, and disingenuous.

By ignoring best environmental analytical and science practices and NEPA requirements the mitigation offered is incomplete, flawed, or non-existent. The Navy needs to fully analyze the potential effects of the proposed actions, develop and implement a strategy of impact avoidance, minimization, and mitigation; and proposed mitigation that is specific, measurable, and resource applicable.

Failure to Comply with Intent of Federal Laws and Regulations

Federal agencies are required to comply with several laws and regulations, including Executive Orders, as part of NEPA compliance for a proposed project. Two of the most relevant of these for the CNMI are Executive Order 12898 Environmental Justice and Executive Order 13045 Protection of Children from

Environmental Health and Safety Risks. The Navy CJMT EIS analysis of environmental justice impacts and impacts to children in particular is flawed and does not meet the intent of the Executive Orders.

Executive Order 12898 directs all federal agencies to identify and address disproportionately high and adverse human health or environmental effects of its programs, policies, and activities on minority populations and low-income populations. **The CJMT EIS analysis acknowledges that the entire population of CNMI is minority and low income, yet makes the astounding conclusion that there would be no disproportionate impact to those populations because all would be impacted equally. This is analogous to determining that it was fair to place a toxic incinerator in a low-income minority town because all those in the town would be similarly affected – as opposed to placing it somewhere else**.

These conclusions do not meet the intent of Executive Order 12898. Using standard social science planning and policy practices, the unavoidable environmental justice analysis conclusions should be that impacts of the Navy CJMT disproportionately affect the minority and low income population of the CNMI. The population of CNMI would be disproportionately impacted compared to other populations. The analysis also should consider the impacts on the Chamorro and Carolinian peoples, two specific minority populations on Tinian.

Executive Order 13045 requires federal agencies to assess environmental health risks and safety risks that would disproportionately impact children. The CJMT EIS fails to adequately evaluate environmental health and safety risk to the children of the CNMI. The CJMT EIS acknowledges that children on Tinian would be exposed to high levels of noise, but concludes that the impacts would be short-term and infrequent and then concludes that the anticipated noise level and frequency would not likely result in health risks to children and impacts would be less than significant without providing any justification for this conclusion. The discussion fails to describe how children could be affected by repeated exposure to high noise levels. The CJMT EIS does not discuss any other potential environmental health or safety risks to children although children could be affected by decreased air quality, water pollution, and hazardous materials left from the proposed training activities.

There appears to have been no analysis of the effects of the current non-live firing training that sporadically occurs on Tinian. In limited meetings with local residents there was clear documentation of effects to the general population and children from this training that includes noise disturbance at homes, broken windows from low aircraft flights, and closing of school for several days because the current training noise so interfered with teaching. This information was easily obtained from meetings with residents and was relayed to the Navy during their limited public outreach efforts – but apparently was ignored during the analysis related to EO 13045.

These inadequate analyses demonstrate a failure to comply with the intent of the Executive Orders to protect children and minority and low-income people. The Navy needs to revise the Environmental Justice and Protection of Children analyses and acknowledge that the proposed project would have significant impacts to these populations. Thus, changes are needed to the EIS to be in compliance with these EOs. This must include one or all of the following: choosing the No Action Alternative as the Preferred Alternative, modifying the Preferred Alternative to satisfy the intent of the Executive Orders, and/or providing applicable mitigation to alleviate the project effects in minority populations and children.

Similarly, the insufficient analysis of project effects and the lack of discussion of how the project will comply with a number of other key federal environmental laws is a major deficiency of the CJMT EIS. A brief summary of some of these deficiencies is included below.

<u>Endangered Species Act</u>

A number of birds, the Marianas fruit bat, and several sea turtle species are protected under the federal Endangered Species Act. Significant impacts are identified for a number of listed species but the EIS is silent on how it will comply with this federal mandate.

Species listed under the Endangered Species Act are the most vulnerable to habitat loss and continued disturbance. The CJMT EIS does not address how the proposed project and the ensuing adverse effects to these species will affect how the USFWS will be able to meet goals that are set out for each individual species in corresponding published Recovery Plans. In addition the analysis of effects to these species fails to use complete baseline data, provides no scientific-based analysis framework, repeatedly jumps to unsubstantiated conclusions, and provides no mitigation. The analysis lacks the context of island ecology and is more appropriate for a project on the mainland affecting a group of common species rather than a group of endangered species on unique island habitats in the South Pacific.

In addition, on October 1, 2015 the USFWS proposed to list Slevin's skink (*Emoia slevini*) and the humped tree snail (*Partula gibba*) as Endangered under the Endangered Species Act. These species have extremely limited occurrences in the CNMI and both were recently found on Pagan Island. A number of plant species also were proposed for listing as Threatened or Endangered that occur in the CNMI. This recent announcement further reinforces the important biodiversity of Pagan Island and the Navy must thoroughly analyze its potential effects to these species; assess the need to conduct further baseline studies on Pagan for plants and animals to comply with the Endangered Species Act requirements for data collection, assessment, and consultation; modify the CJMT DEIS accordingly, and provide additional time for agency and public comment.

<u>Marine Mammal Protection Act</u>

Sperm and humpback whales, among other marine mammals are known to use the shallow waters around both Tinian and Pagan Islands. The EIS provides only a cursory assessment of the existing conditions and no science-based analysis of the potential effects of construction and operation of the training proposal. There is no discussion on how the project would comply with the Marine Mammal Protection Act.

The CJMT EIS does not use the standard of Best Available Science in both the discussion of existing conditions and in the analysis of effects, provides unsubstantiated and unsupported conclusions, and repeatedly uses the term "less-than-significant" where the MMPA uses a lesser threshold standard of "negligible impact". The EIS is not compliant with the MMPA and needs to be revised.

Safe Drinking Water Act

Groundwater contamination by the massive amounts of proposed munitions on both Tinian and Pagan are of primary concern to the people of these islands. **There has been no baseline established by the Navy of the current groundwater conditions, the EIS ignores recent and relevant data on munition effects to soil and groundwater (EPA 2012), and the EIS does not use the resource data available in a USGS study of the groundwater on Tinian to analyze potential effects (Gingerich and Yeatts. 2000). The EIS is silent on how the project will comply with the Safe Drinking Water Act**.

To satisfy NEPA regulations the Navy must: 1) collect data to adequately characterize the condition of groundwater on Tinian and Pagan, 2) use the EPA and other available scientific reports to fully evaluate the threat to soil and groundwater contamination from the proposed action, 3) develop a revised EIS with changes to avoid and/or mitigation adverse effects, and 4) circulate the new document to the public and agencies for comment.

Clean Water Act

The EIS similarly disregards the parameters of the Clean Water Act, does not include a thorough analysis of the effects to the limited surface waters on Tinian and Pagan, does not provide a context of effects between ground and surface waters, and provides no framework for compliance with the Clean Water Act. Wetlands and other surface waters on Tinian and Pagan will be affected from contamination from spent munitions, erosion, and loss of vegetation on these islands. No information is provided on how the Navy intends to comply with the provisions of the Clean Water Act for protection of "waters of the US, including wetlands."

Inadequate Cumulative Effects Analysis

Cumulative impacts are those that result from the incremental impact of the proposed action when added to other past, present, and reasonably foreseeable future actions. NEPA requires that proposed actions be assessed on two scales – the incremental effect of the combined proposed actions on each resource area and the combined effect of other Navy actions proposed for the project area. Neither is included in the CJMT EIS.

When determining cumulative effects one needs to consider:

- Additive, countervailing, and synergistic effects.
- A timeframe including and beyond the life of the proposed action.
- And the sustainability of resources, ecosystems, and human communities (CEQ 1997).

The EIS analyzes the effects of the project in isolation – noise, vegetation removal, continual disturbance, munitions residue, erosion – each are analyzed separately within a resource area discussion, but there is no acknowledgement that each of these separate effects can have a corresponding holistic and additive effect on any given resource. This compartmentalization of the effects analysis does not adhere to a science-based, best practices framework and does not comply with NEPA requirements.

Of additional concern is the cursory consideration of cumulative effects outside of the proposed action – including a number of Navy training activities. Other Navy and live-firing activities adjacent to and including Tinian and Pagan include the Mariana Islands Training and Testing proposal (MITT), the Mariana Islands Range Complex (MIRC), and the Guam and Northern Mariana Islands Divert Activities and Exercises. These recent Navy proposals include air, sea, and land exercises; live fire exercises; air landing exercises among others; and they include the two islands under consideration for the current CJMT EIS – Tinian and Pagan.

Each of these Navy training activities has overlapping and cumulative effects to the many of the same resources under consideration in the CJMT EIS. **The analysis of cumulative effects suffers the same inadequacies as described above for the resource area impact analysis. The effects analysis includes no significance thresholds; previous studies or literature that could provide context or substantiate conclusions are not included; and conclusions are not based on an analytic framework and appear speculative at best**. Professional environmental analysis practices and NEPA/CEQ regulations require that a thorough research and review effort be conducted to gain a full understanding of the range of projects – from the Navy or other agencies – that could affect the resources within the project area. In this case, it is the same project proponent – the Navy – that is implementing similar projects with overlapping and cumulative resource effects. Yet no details on these other proposed training activities are provided and there is no analysis of how these actions will interact with the actions of the CJMT. The Navy has not complied with NEPA requirements regarding a cumulative effects analysis.

Instead, the Navy CJMT EIS simply summarizes portions of conclusions in earlier sections and provides a laundry list of potentially affected resources. Impact conclusions are unsubstantiated and include no previous discussion of how other Navy actions may affect a particular resource. *There would be no cumulative impact to marine biological resources on Pagan* is a typical unsupported statement. When vague and general cumulative impacts are identified, no mitigation is proposed.

The Navy must address these deficiencies and include the full range of activities that affect the resources of Tinian and Pagan Islands and the interconnected resources.

Summary

The Navy CJMT DEIS fails to comply with NEPA and CEQ regulations regarding the presentation of baseline information, effects analysis, standard science and planning analysis practices, significance threshold determinations, avoidance and minimization of effects, and does not comply with a number of other federal regulatory statutes. The deficiencies in the document are numerous, pervasive, substantial, and significant enough to require a thorough revision and an additional public and agency comment period.

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COX ET AL-1991-CONSERVATION BIOLOGY

Essay

Flying Foxes as Strong Interactors in South Pacific Island Ecosystems: A Conservation Hypothesis

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Abstract: *The dependency of highly endemic island floras on few potential pollinators in depauperate island faunas suggests that pollinators and seed dispersers may be crucial in the preservation of biodiversity in isolated oceanic islands. We discuss the hypothesis that flying foxes are "strong interactors" in South Pacific islands where they serve as the principal pollinators and seed dispersers. This suggests that the ongoing decline and ultimate extinction of flying fox species on Pacific islands may lead to a cascade of linked plant extinctions. We propose an empirical test of this hypothesis: comparisons of plant reproductive success in Guam, which has virtually lost its flying fox populations, and Samoa, where significant populations remain.*

Resumen: *La dependencia de floras isleñas altamente endémicas en algunos polinizadores potenciales en faunas isleñas depauperizadas sugiere que los polinizadores y los dispersadores de semillas pueden ser cruciales en la conservación de la diversidad biológica en islas oceánicas aisladas. Discutimos la hipótesis de que los murciélagos frugívoros (*Pteropus *sp.) son fuertes interactores en las islas del Pacífico sur, en donde funcionan como los principales agentes de polinización y de dispersión de semillas. Esto sugiere que la contínua disminución y futura extinción de las especies de murciélagos frugívoros podrían llevara una extinción de plantas en cadena. Hemos propuesto una prueba empírica de esta hipótesis, mediante la comparación del éxito reproductivo de las plantas en Guam, que prácticamente ha perdido sus poblaciones de murciélagos frugívoros, con el de Samoa, donde persisten poblaciones importantes.*

Introduction

The initial models for keystone species were predators in intertidal communities, where removal of predators led to a dramatic drop in the diversity of other animal species (Paine 1966). Herbivores can also be important

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in maintaining diversity of plant communities (Harper 1977; Owen-Smith 1987, 1989; Brown & Heske 1990), but little attention has been paid to pollinators and seed dispersers as "strong interactors" (*sensu* Paine 1980).

Are There Ecosystems in Which Pollinators and Seed Dispersers Are Strong Interactors?

Is it possible that pollinators and seed dispersers may similarly maintain species diversity in some ecosystems? By this we are not asking whether pollinators and seed dispersers are important to plant communities. Nor are we questioning whether pollinators are important for the survival of specific plants, since in tightly coevolved pollination systems, extinction of one partner can lead to the extinction of the other (Feinsinger 1983). Yet the loss of a wasp species responsible for pollinating a single species of epiphytic orchid is unlikely to alter the trajectory of a rain forest community as much as the loss of the sole pollinator of a major canopy-level tree. Similarly, the loss of a species responsible for dispersing the seeds of an uncommon saprophytic herb is unlikely to significantly affect the plant community, yet the demise of the seed disperser of a group of rain forest gap species will.

We suggest that ecosystems in which the loss of a few species of pollinators or seed dispersers would lead to a "cascade of linked extinctions" (Myers 1986) have three characteristics:

1. Ecological relationships between pollinators or seed dispersers and plant species should generally be asymmetrical and skewed in favor of the animals, that is, the reproduction and survival of a plant species should be far more threatened by loss of a pollinator or seed disperser than the reproduction and survival of a pollinator or seed disperser is threatened by loss of a plant species it feeds on.
2. Species diversity of pollinator and seed disperser guilds must be extremely low, so that recruitment of alternative pollinators or seed dispersers by a plant is generally unlikely.
3. Plant breeding systems, dispersal mechanisms, and population structures should preclude rapid evolutionary adjustment to loss of major pollinators or seed dispersers.

What type of ecosystems have these characteristics? Previous studies on the relationships of pollinators, frugivores, and plant biodiversity have tended to focus on continental areas, particularly in the Neotropics where some plant-pollinator and plant–seed disperser asymmetries have been found (Gilbert 1978; Howe & Vande Kerckhove 1979; Howe & Smallwood 1982; Dobat & Peikert-Holle 1985; Estrada & Fleming 1986; Fleming et al. 1987; Fleming 1988). For example, Augspurger (1980) has found that *Hybanthus prunifolius* is dependent for pollination on a single species of bee, which, however, feeds on many different types of flowers. Similarly, Howe (1983) and Howe and Westley (1986) found asymmetrical relationships between toucans, which feed on many species of fruits, and certain *Virola* species that depend entirely for seed dispersal on the toucans.

Our second postulated requirement, depauperate guilds of pollinators and seed dispersers, is not likely to be commonly satisfied in species-rich continental tropical areas, although high equatorial mountains or temperate alpine and tundra regions dominated by a few small guilds of pollinators (Pleasants 1983) may qualify. Many continental temperate plant species have numerous floral visitors; Schemske (1983) found that most of a group of 55 species of Compositae have over 20 species of visitors.

The third requirement, the inability of plants to make rapid evolutionary responses to loss of pollinators or dispersers, might be satisfied in reproductively isolated, small, obligately outcrossed plant populations. It is unlikely to be satisfied in temperate populations where interpopulation gene flow via both long-distance pollen (Lertzman & Gass 1983) and seed dispersal is possible. Again, isolated ecological islands such as mountaintops or desert springs may qualify, as may many lowland tropical rain forests characterized by plant reproductive isolation, obligate outcrossing (i.e., dioecism), small population size, low genetic diversity, and dependence on animal vectors (Ashton 1976; Gilbert 1978).

Pollinators and Seed Dispersers as "Strong Interactors" in Isolated Oceanic Islands

In some, and perhaps many, isolated oceanic islands all three of our criteria are met. Several examples are noted below.

A. Asymmetrical Plant–Animal Relationships

Evolutionary relationships between plants and pollinators in oceanic islands do tend to be highly asymmetrical. In Samoa, for example, *Freycinetia reineckei* (Pandanaceae), a dioecious liana, is pollinated by the flying fox *Pteropus samoensis* (Cox 1982, 1984, 1990). Experiments with the few hermaphroditic plants produced show that *P. samoensis* is far more likely to damage male and hermaphroditic spikes during pollination, causing dioecism to be maintained in the population (Cox 1982). However, there is no apparent reciprocal evolutionary effect of *F. reineckei* on the flying foxes, which feed on a wide range of plants. Since the number of plant species vastly exceeds the number of potential pollinators in Samoa (see next section), many plant-pollinator relationships in Samoa are likely to be asymmetrical.

B. Depauperate Pollinator and Seed Disperser Guilds

Isolated tropical oceanic islands tend to be characterized by depauperate pollinator and seed disperser guilds. Even some large isolated temperate island groups such as New Zealand have small pollinator faunas compared to continental areas (Lloyd 1985). In South Pacific islands, plant and animal diversity decreases with increasing distance eastward from Australasia. Consequently, the diversity of pollinators and seed dispersers is lower in Samoa than in New Caledonia or Fiji, and lower still in Tahiti.

The low diversity of pollinators and seed dispersers in isolated oceanic islands is striking when contrasted with the high diversity of pollinators and seed dispersers in continental tropical areas. For example, in Samoa there are no native Apidae, no native Anthophoridae, and only 11 native Semoon bee species (Bryan 1930). By contrast, in the lowland Guanacaste forest of Costa Rica there are over 40 species of medium-large species of bees alone (Frankie et al. 1983). Similarly, in Samoa, hawk moths total only six species (Bryan 1930), while the Guanacaste forest has 66 species of sphingid moths (Haber 1983). Samoa has only 9 total species of flower-visiting birds, while Costa Rica has over 50 species of hummingbirds alone (Stiles 1983). Samoa has only 2 species of flower-visiting bats, while there are over 16 species of phyllostomid bats that visit flowers in Costa Rica (Gardner 1977; Wilson 1983). Thus most of the Samoan flora (over 800 angiosperm species) must be pollinated by a low assemblage of animals while comparable continental areas have many more species of pollinators available.

As a result, plants on isolated oceanic islands are extremely vulnerable to extinction due to pollinator loss. In Hawaii, *Freycinetia arborea* (Pandanaceae) was pollinated by species of now extinct Hawaiian birds and saved from extinction only by the fortuitous introduction of a new pollinator (Cox 1983*b*). Given its importance in Hawaiian vegetation and the diverse invertebrate community that lives in the leaf axils, the demise of this liana would probably have had a significant effect on Hawaiian ecosystems.

C. Inability to Adjust to Pollinator and Seed Disperser Loss

Plants on remote oceanic islands are reproductively isolated from source floras. Founder effects, small population size, negligible gene flow between islands, infrequent immigration events, and (in the tropical Pacific) episodic mortality from typhoons, droughts, and other disturbances have probably contributed to genetic divergence among island plant populations. As a result, speciation events in such island taxa as the ***Pandanus tectorius*** complex have been frequent (Cox 1985, 1990). The loss of long-distance dispersal mechanisms in island plants, other than strand and littoral species, is pronounced. Outside the strand and littoral areas, abiotic dispersal mechanisms are similarly uncommon. Thus oceanic island plant populations have evolved toward increased dependence on the few indigenous animals and show an inability to adjust to loss of pollinators or seed dispersers.

The potentially disastrous consequences of such dependence are illustrated by the *Sideroxylon sessiliflorum* and *S. grandiflorum* (Sapotaceae) trees in Mauritius, which were unable to adjust to the extinction of the large vertebrates (dodos, giant tortoises, or both) that had formerly dispersed their seeds (Temple 1977; Iverson 1987). Seedling recruitment to the *Sideroxylon* populations virtually ceased, and through the years the age structure of the population shifted until only a few, apparently old individuals remained. The probable extinction of the trees was alarming since these *Sideroxylon* trees in turn supported a diverse community of epiphytic plants, invertebrates, and birds. Although interpretations of some aspects of the evidence are controversial (Owadally 1979; Iverson 1987), feeding experiments with turkeys produced the first seedlings in decades (Temple 1977).

Flying Foxes as Keystone Pollinators and Seed Dispersers in the Southwest Pacific

Unfortunately, today a similar inadvertent experiment involving island pollinators and seed dispersers is occurring: the extinction of flying foxes on Pacific islands. These important pollinators and seed dispersers have suffered serious population declines throughout much of their range due primarily to habitat loss and overhunting, locally exacerbated by typhoons and introduced predators (Wodzicki & Felten 1975, 1980; Racey 1979; Cheke & Dahl 1981; Cox 1983*a;* Carroll 1984; Wiles 1987*a,b;* Falanruw 1988; Pierson & Rainey, in press). Between 1975 and 1990, the decline was greatly accelerated by commercial importation of 8000–29,000 frozen flying foxes per year into Guam to supply a luxury food market (Wiles & Payne 1986; Wiles in press). Although a number of species affected by the trade were listed on Appendix II of the CITES treaty in 1987, it was not until after most of these species were moved in 1989 to Appendix I and the remainder of the genus placed on Appendix II (Bräutigam & Elmqvist 1990), that the United States government began to implement mandated controls.

A. Flying Foxes in South Pacific Islands

Flying foxes, belonging primarily to the genus *Pteropus*, are the only indigenous frugivorous-nectarivorous mammals on most oceanic islands of the Pacific. Although *Pteropus* ranges from Madagascar to the Cook Islands, its primary distribution is in the Pacific, 46 of the 56 species occurring east of the Indian Ocean. Most species have limited ranges, with 38 (67%) confined to land areas of less than 50,000 km^2 (Rainey & Pierson, in press).

Flying foxes have few natural predators (primarily raptors and snakes), but their limited reproductive capacity makes them vulnerable to unnatural predation (overhunting and introduced predators) and catastrophic events (e.g., typhoons and epidemics). Females of most *Pteropus* species have a maximum of one infant per year and do not produce their first young until they are one to two years old (Asdell 1964; Nelson 1964). Their pregnancies last from 4 to 6 months (Neuweiler 1969; Racey 1973), and they care for their young for up to a year (Pook 1977).

B. Flying Foxes as Pollinators and Seed Dispersers

Pteropus species have been reported to visit over 92 genera of plants in 50 different families (Dobat & Peikert-Holle 1985; Marshall 1985; Wiles & Fujita, in press; Pierson and Rainey, in press), while in the southwest Pacific islands, just two species of flying fox, *Pteropus samoensis* and *P. tonganus*, have been found to visit over 36 different species of plants for flowers or fruit (Sykes 1970; Wodzicki & Felten 1975, 1980; Cox 1983*a,b*, 1984; Cox et al. 1991).

Although the importance of bats as pollinators and seed dispersers in continental areas is clearly documented (van der Pijl 1956; Baker & Harris 1959; Dobat & Peikert-Holle 1985; Marshall 1985; Estrada & Fleming 1986; Fleming et al. 1987; Fleming 1988; Thomas et al. 1988), given the paucity of other vertebrate pollinators and seed dispersers on isolated oceanic islands, it is likely that maintenance of much of the plant diversity of the high islands of the southwest Pacific depends on flying foxes. These plants, in turn, probably support much of the animal diversity of the islands (Terborgh 1986).

The importance of flying foxes as pollinators in the Pacific can be inferred from studies of plants that have many pollinators in continental areas but are apparently dependent on flying foxes in remote Pacific islands. For example, the pollination ecology of *Ceiba pentandra* (Bombacaceae) has been studied in West Africa (Baker & Harris 1959), India (van der Pijl 1935), Brazil (Carvalho 1960), Peru (Janson et al. 1981), and Mexico (Toledo 1977), where its flowers have been found to be visited by a large suite of insects, birds, nonflying mammals, and bats. Analysis of its reproductive ecology in Samoa, where it is an aboriginal introduction (Whistler, in press), revealed a single pollinator, the flying fox *Pteropus tonganus* (Elmqvist et al., in press).

A similar example is the liana genus *Freycinetia*. In continental areas, *Freycinetia* species are pollinated by a variety of vertebrates ranging from small birds to large squirrels, yet in Samoa, *Freycinetia reineckei* relies on only two pollinators, the flying fox, *Pteropus samoensis*, and the native starling, *Aplonis artifucus* (Cox 1982, 1984).

In Samoa, flying foxes play an important role as seed dispersers (Cox et al., in press), where the asynchronous fruiting phenology of highland and lowland plant populations provides the highly mobile flying foxes with a steady food resource. During the dry season, 80–100% of the seed rain in lowland forest is generated by flying foxes, some of the seeds being carried from distant lowland hills. We have recorded flying fox–dispersed seed densities away from roosts as high as 36 fruits/m^2, with extreme variability in species composition of the seed rain. Flying foxes appear to be the single most important seed dispersers in Samoa and are probably the most important pollinators as well.

C. A Proposed Test of the Hypothesis

The importance of flying foxes as pollinators and seed dispersers in isolated oceanic islands could be tested by examining the effects of their presence and absence in Samoa and Guam. The virtual extirpation of flying foxes on Guam allows a test of our "strong interactor" hypothesis, since Guam can be compared to Samoa, where flying fox populations persist. The reproductive ecology of selected plant species found in both Guam and Samoa could be studied for differences in pollination success, seed dispersal, and seedling recruitment.

We suggest studies in Guam because of the very recent and rapid declines in flying fox populations on the island (Wiles 1987*a,b*). One species, *Pteropus tokudae*, has gone extinct in recent years (Wiles 1987*a*). Although the other species, *Pteropus mariannus*, continues to exist as a few individuals, it has probably ceased to fulfill its role in the ecosystem as an important pollinator and seed disperser. We have preliminary evidence of pollination failure and reduced fruit set for several plant species in Guam: during a week-long study, most fruits in the forests were found to have fallen beneath the parent trees, with none showing signs (i.e., teeth marks) of having been dispersed by bats or other animals. But far more data are needed to corroborate these preliminary indications.

We suggest Samoa as a comparative site since it has floristic affinities to Guam, and preliminary floral, faunal, and habitat surveys are available. Additionally, there is a strong conservation ethic in Samoan culture, with an impetus to protect native resources; substantial tracts of forest supporting viable bat populations still remain, with four rain forest preserves having recently been established in Western and American Samoa (Cox 1988; Cox & Elmqvist, in press).

Conclusion

We suggest that pollinators and seed dispersers may structure the ecosystems of remote islands in the same fashion that predators structure some continental and intertidal communities. This hypothesis has profound implication for island conservation strategies, since it suggests that the identification and protection of pollinators and seed dispersers in oceanic islands should be a conservation priority. Three Pacific island flying fox species have recently gone extinct, and many others are experiencing severe population declines (Pierson & Rainey, in press). Given the importance of flying foxes as major pollinators and seed dispersers in the South Pacific, substantive enforcement of the recent CITES listings for Pacific flying foxes may be crucial, not only for flying fox survival, but for the maintenance of entire Pacific island floras as well.

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We thank the parties to the Convention on International Trade in Endangered Species (CITES) for their unanimous decision to support the joint Sweden–US proposal to limit trade in Pacific flying foxes, and the indigenous people of the South Pacific for their insights into this problem. We are particularly grateful to Gary Wiles, Guam Division of Aquatic and Wildlife Resources, for assistance in Guam. This study was supported by a N.S.F. Presidential Young Investigator Award BSR-8452090, and a grant from the World Wildlife Fund, Sweden. Field work in Guam was partially supported by a grant from Bat Conservation International.

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CAMP TR029

TINIAN AGUIGUAN LAND BIRDS FINAL

Technical Report HCSU-029

STATUS AND TRENDS OF THE LAND BIRD AVIFAUNA ON TINIAN AND AGUIGUAN, MARIANA ISLANDS

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Abstract

Avian surveys were conducted on the islands of Tinian and Aguiguan, Marianas Islands, in 2008 by the U.S. Fish and Wildlife Service to provide current baseline densities and abundances and assess population trends using data collected from previous surveys. On Tinian, during the three surveys (1982, 1996, and 2008), 18 species were detected, and abundances and trends were assessed for 12 species. Half of the 10 native species—Yellow Bittern (*Ixobrychus sinensis*), White-throated Ground-Dove (*Gallicolumba xanthonura*), Collared Kingfisher (*Todiramphus chloris*), Rufous Fantail (*Rhipidura rufifrons*), and Micronesian Starling (*Aplonis opaca*)—and one alien bird—Island Collared-Dove (*Streptopelia bitorquata*)—have increased since 1982. Three native birds—Mariana Fruit-Dove (*Ptilinopus roseicapilla*), Micronesian Honeyeater (*Myzomela rubratra*), and Tinian Monarch (*Monarcha takatsukasae*)—have decreased since 1982. Trends for the remaining two native birds—White Tern (*Gygis alba*) and Bridled White-eye (*Zosterops saypani*)—and one alien bird—Eurasian Tree Sparrow (*Passer montanus*)—were considered relatively stable. Only five birds—White-throated Ground-Dove, Mariana Fruit-Dove, Tinian Monarch, Rufous Fantail, and Bridled White-eye—showed significant differences among regions of Tinian by year. Tinian Monarch was found in all habitat types, with the greatest monarch densities observed in limestone forest, secondary forest, and tangantangan (*Leucaena leucocephala*) thicket and the smallest densities found in open fields and urban/residential habitats. On Aguiguan, 19 species were detected on one or both of the surveys (1982 and 2008), and abundance estimates were produced for nine native and one alien species. Densities for seven of the nine native birds—White-throated Ground-Dove, Mariana Fruit-Dove, Collared Kingfisher, Rufous Fantail, Bridled White-eye, Golden White-eye (*Cleptornis marchei*), and Micronesian Starling—and the alien bird—Island Collared-Dove—were significantly greater in 2008 than 1982. No differences in densities were detected between the two surveys for White Tern and Micronesian Honeyeater. Three native land birds—Micronesian Megapode (*Megapodius laperouse*), Guam Swiftlet (*Collocalia bartschi*), and Nightingale Reed-Warbler (*Acrocephalus luscinia*)—were either not detected during the point-transect counts or the numbers of birds detected were too small to estimate densities for either island. Increased military operations on Tinian may result in increases in habitat clearings and the human population, which would expand human-dominated habitats, and declines in some bird populations would be likely to continue or be exacerbated with these actions. Expanded military activities on Tinian would also mean increased movement between Guam and Tinian, elevating the probability of transporting the brown tree snake (*Boiga irregularis*) to Tinian.

Introduction

The Department of Defense (DOD) has proposed expanding military operations in the Mariana Islands. To determine the future impacts of military operations on bird populations on these islands, the DOD contracted the U.S. Fish and Wildlife Service, Pacific Islands Fish and Wildlife Office, to coordinate avian surveys on the islands of Tinian and Aguiguan in the Commonwealth of the Northern Mariana Islands (CNMI). The survey data will be used to establish population baseline information to compare with any later change in status and distribution of the birds.

Current avian population estimates were calculated for the whole island for both Tinian and Aguiguan and by regions for Tinian Island. These estimates were compared with results from a previous survey of both islands that was undertaken in 1982 by Engbring *et al*. (1986), yielding trends spanning 27 years. On Tinian, trends in bird populations across the island and within regions were compared from three surveys: the 1982 Engbring *et al*. survey, a survey in 1996 by the U.S. Fish and Wildlife Service (unpublished data, Lusk *et al*. 2000), and again in 2008. Aguiguan was surveyed in 1982 and 2008, and end-point comparisons were used to assess population changes. Particular attention was given to assess the status of the Tinian Monarch. Formerly listed as an endangered species, the monarch was delisted on September

21, 2004 (69 FR 65367) and is being monitored by the U.S. Fish and Wildlife Service through field surveys of distribution and abundance and tracking of land use and development on Tinian.

Methods

Survey area

Tinian: Tinian is the second largest of the CNMI islands at 101.01 km^2 (15^o 00` N, 145$^o$ 35` E). The island consists of low-lying plateaus and a gentle limestone ridge dominated by Puntan Carolinas (elevation 196 m). The vegetation of Tinian currently consists of mixed second-growth forests, grassy savannas, and introduced forests, most of which are tangantangan (*Leucaena leucocephala*) thickets (Engbring *et al*. 1986). The little native vegetation that remains on Tinian (5%; Engbring *et al*. 1986) has been greatly altered by centuries of human use and non-native species and is basically confined to a few cliffs and adjacent steep limestone slopes (Engbring *et al*. 1986).

Aguiguan: Aguiguan is a small, uninhabited island located 8 km southwest of Tinian (7.09 km^2; 14^o 51` N, 145$^o$ 33` E). It is made up of several concentric plateaus bounded by steep scarps, and the topmost plateau is about 150 m in elevation. Like other CNMI islands, the vegetation on Aguiguan has been extensively altered by human activity, so the available native forest is limited. In addition, the island has a large feral goat (*Capra hircus*) population, which continues to alter the native forest.

Bird surveys

On Tinian, the baseline survey conducted between 27 April and 8 May 1982 sampled a total of 216 stations on 10 transects with representative island-wide coverage across geography and habitats (Engbring *et al*. 1986; Figure 1). Placement of transects was random-systematic (Engbring *et al*. 1986). These transects were located and resurveyed during both the 1996 (28 August–1 September) and 2008 (14–19 June) surveys. An additional four transects were sampled during the 2008 survey for a total of 253 stations (transect 11 – 9 stations; transect 12 – 9 stations; transect 13 – 14 stations; and transect 14 – 5 stations). The four transects were added to increase the sampling of native limestone forest and improve density estimates for Tinian Monarch.

On Aguiguan, an island-wide survey consisting of 66 stations on four transects (random-systematic placement) was conducted on 2 and 3 June 1982, and a partial survey (transects 1 and 2 only) was conducted on 10 and 11 March 1982 (Engbring *et al*. 1986; Figure 2). Data from only the June survey were used in this study because all stations were sampled and the survey month coincides with the 2008 survey. All four transects were located and resurveyed during the 2008 (25–27 June) survey. An additional transect of 14 stations was sampled during the 2008 survey for a total of 80 stations. This transect was added to increase the numbers of birds detected and to sample the top-most plateau; however, placement of this transect on the plateau was random.

All surveys followed standard point-transect methods, consisting of eight-minute counts, where horizontal distances to all birds heard and/or seen were measured and recorded (see Engbring *et al*. 1986 for details). Sampling conditions recorded included cloud cover, rain, wind, noise level, and habitat type, and these were later used as covariates in density calculations (see Population status below). Counts commenced at sunrise and continued up to four hours and were conducted only under prescribed conditions.

Stations were surveyed by two observers in 1982 and one observer in 1996 and 2008. Data from only one counter were used for each station from the 1982 Tinian surveys, and the best counters were identified based on their experience and survey proficiency. Engbring *et al*. (1986) analyzed bird detections from all observers to estimate bird densities. For our analysis, we used detections from only one observer to

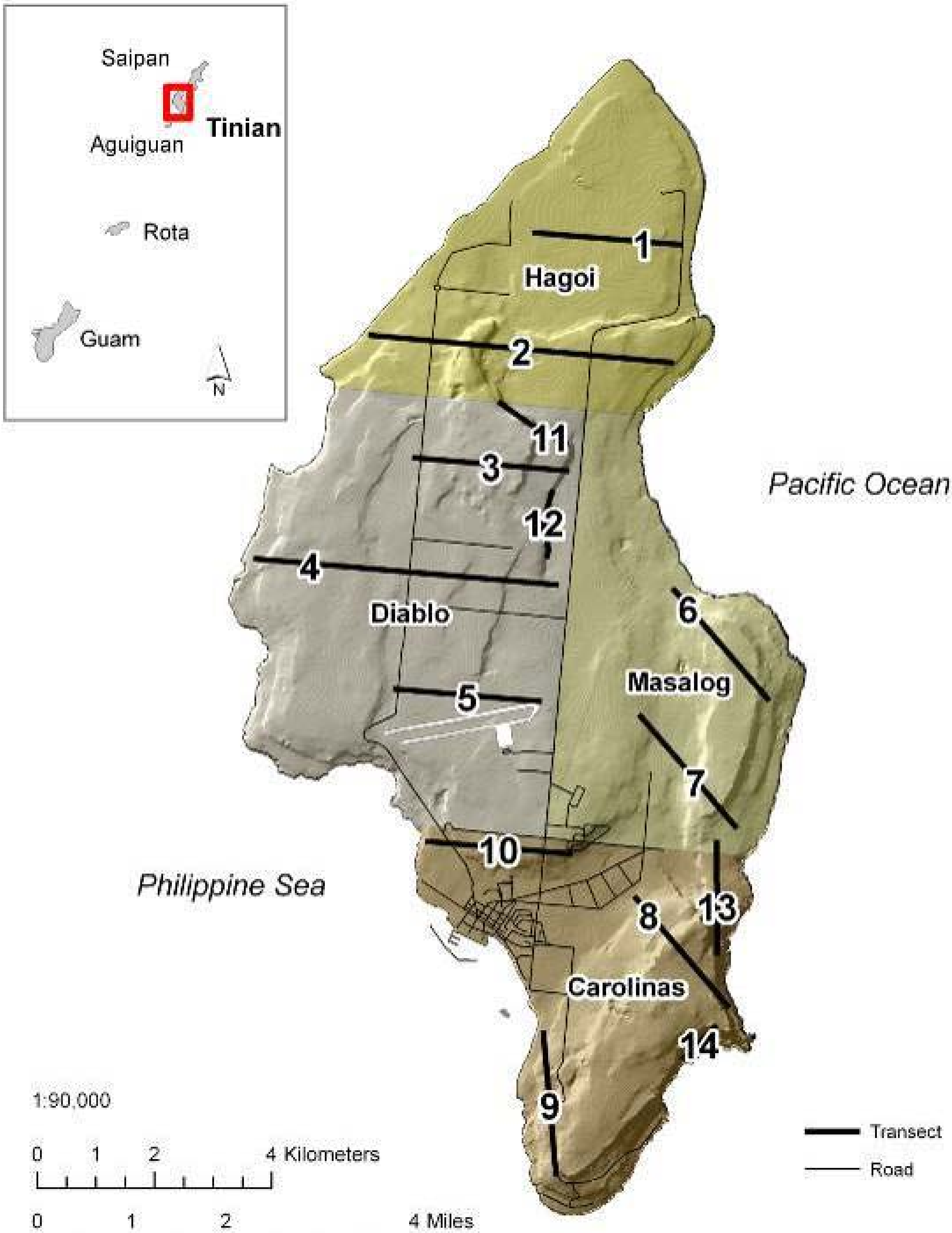

Figure 1. Island of Tinian, Commonwealth of the Northern Mariana Islands, showing the survey transects and regions (as defined by Engbring *et al.* 1986). Transects 1–10 were counted during all three surveys, and transects 11–14 were established and counted during the 2008 survey.

recalculate densities for the 1982 Tinian survey, thus matching the 1996 and 2008 survey effort. Calculating densities from only one of the counters is a conservative approach and ensures sampling independence. This approach approximately halved the number of birds detected; however, our density

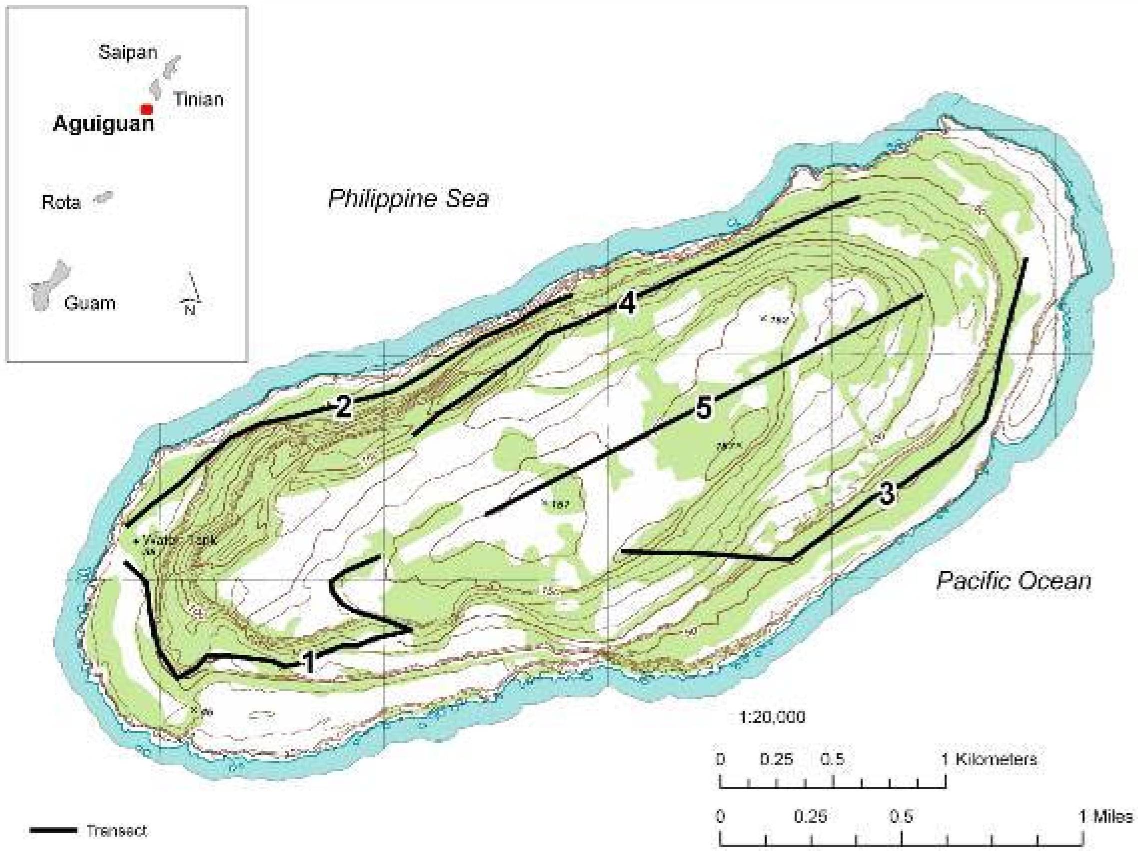

Figure 2. Island of Aguiguan, Commonwealth of the Northern Mariana Islands, showing the survey transects. Transects 1–4 were counted during both the 1982 and 2008 surveys, whereas transect 5 was established and counted during the 2008 survey.

estimates were generally greater than, but otherwise similar to, those of Engbring *et al*. (see their Table 8; 1986). On Tinian the 95% confidence intervals bracketed Engbring *et al*.'s estimates for all but four birds—Mariana Fruit-Dove, Tinian Monarch, Rufous Fantail, and Bridled White-eye. Differences may have resulted from analytical procedures such as selecting different truncation distances, selecting different models to estimate densities, and analytical advances in distance sampling (see Johnson *et al*. 2006), in addition to estimating densities using detections from only one of the counts (Tinian only). Data from both counters were used to estimate 1982 densities on Aguiguan because it was a small data set, and the sampling effort was adjusted appropriately.

Population status

Population status was calculated as density (birds/km^2) and number of birds (density by habitat type multiplied by habitat type area). Density was calculated using the program DISTANCE, version 5.0, release 2 (Thomas *et al*. 2006) from species-specific global detection functions, where data were post-stratified by survey. Data were right-truncated to facilitate model fitting (Buckland *et al*. 2001:16). Candidate models included half-normal and hazard-rate detection functions with expansion series of order two (Buckland *et al*. 2001:361, 365). Sampling covariates were modeled in the multiple-covariate distance engine of DISTANCE (Thomas *et al*. 2006, Marques *et al*. 2007). The model with the lowest Akaike Information Criterion (AIC) was used to select the detection function that best approximated the data. Covariates (sampling conditions, habitat types, and survey year) were used to generate the global detection function when the best approximating model was improved by four or more AIC units (Appendix 1). Variances and confidence intervals were derived by log-normal based methods. Survey-specific, density-by-station values were generated for the population trends analyses (see Population trends below) from the global detection function using the post-stratification-by-sample option.

Area of habitat types came from Engbring *et al*. (1986) and U.S. Fish and Wildlife Service (2008). The area of habitat types was not available for the 1996 Tinian survey; therefore, we used the area by habitat types from Engbring *et al*. to calculate the 1996 numbers of birds. This may slightly underestimate the population size if there was more secondary forest in 1996 than 1982. Agriculture habitat type (combined agroforestry and cultivated habitat type classifications) was not used to calculate numbers of birds because the area of this habitat is very small relative to the island (< 2%), the area of the agriculture habitat type has declined (190 ha in 1982 to 174 ha in 2008; U.S. Fish and Wildlife Service 2008), and insufficient numbers of stations were established in the agriculture habitat type to produce reliable density estimates (one in 1982, four in 1996, and two in 2008), thus it was under-sampled. In addition, coastal and urban/residential habitat types were inconsistently and under-sampled (coastal: three stations in 1982, one in 1996, and zero in 2008; urban/residential: zero stations in 1982 and 1996, and seven in 2008), and were not used in calculating population estimates. On Aguiguan, the 1982 estimates of the area of habitat types were not reliable; therefore, numbers of birds were calculated only for the 2008 survey.

Population trends

Change in bird density among the three annual estimates on Tinian was assessed with repeated measures analysis of variance (ANOVA: PROC MIXED; SAS Institute Inc., Cary, NC). To stabilize the error variance, density-by-station values were ln(density+1) transformed. Repeated measures ANOVA also was used to assess change in bird density within regions among the three annual estimates. Stations were treated as the random factor, and because the number of repeated measures was too small to fit a covariance model, we assumed the variance-covariance structure was a compound symmetry, homogeneous-variance model (Littell *et al*. 1996). Degrees of freedom was adjusted using the Kenward-Roger adjustment statement, and a Tukey's adjustment was used to control experiment-wise alpha = 0.05 for multiple-comparison procedures. A further analysis was conducted to assess differences by habitat type for Tinian Monarch from the 2008 survey using a one-way ANOVA (PROC MIXED) with the same options as those used in the repeated measures models. The agriculture habitat was dropped from this analysis because only two stations were sampled within the habitat during the 2008 survey.

End-point comparisons of the Aguiguan bird densities were compared using a two-sample *z*-test. Comparing density estimates using *z*-tests is the recommended method (L. Thomas, pers. comm.) and is an extension of the method listed in Buckland *et al*. (2001:353).

Results

Tinian

A total of 18 species was detected during one or more of the three surveys on Tinian (Table 1). Sufficient numbers of individuals were detected for 10 native and two alien species to calculate density and abundance estimates. Bridled White-eye and Rufous Fantail were the most abundant birds, whereas White-throated Ground-Dove and Yellow Bittern were the least abundant birds (Table 2). Half of the 10 native species—Yellow Bittern, White-throated Ground-Dove, Collared Kingfisher, Rufous Fantail, and Micronesian Starling—have increased since 1982 (Table 3, Figure 3). Three native birds—Mariana Fruit-Dove, Micronesian Honeyeater, and Tinian Monarch—have decreased in the same period. Although these declines were not linear (Figure 3), the overall changes between 1982 and 2008 were significant (Table 3). Trends for the remaining two native birds—White Tern and Bridled White-eye—were considered relatively stable. The alien bird—Island Collared-Dove—increased since 1982 or remained relatively stable, respectively (Tables 2 and 3, Figure 3). Although Eurasian Tree Sparrow densities increased 98% from 2 to 110 birds/km^2 between 1982 and 2008, their densities were not estimated well enough to make strong conclusions, and we conclude they have remained relatively stable.

Table 1. List of birds detected from three different point-transect surveys on Tinian. In 1982 and 1996, 216 stations were sampled on 10 transects, and in 2008, 253 stations were sampled on 14 transects (one station sampled twice). The number of stations occupied (# Stns Ocpd), birds detected (# Dect), indices of percent occurrence (% Occ), and birds per station (BPS) were calculated. Nomenclature generally follows the AOU checklist and Reichel and Glass (1991) with updates. Density estimates were produced for birds in bold.

		1982				1996				2008			
Species	Scientific Name	# Stns Ocpd	# Dect	% Occ	BPS	# Stns Ocpd	# Dect	% Occ	BPS	# Stns Ocpd	# Dect	% Occ	BPS
Red Junglefowl	*Gallus gallus*	45	105	20.8	0.49	0	0	0.0	0.00	45	77	17.7	0.30
White-tailed Tropicbird	*Phaethon lepturus*	0	0	0.0	0.00	0	0	0.0	0.00	3	5	1.2	0.02
Yellow Bittern	*Ixobrychus sinensis*	10	10	4.6	0.05	16	18	7.4	0.08	34	38	13.3	0.15
Pacific Reef-Egret	*Egretta sacra*	1	1	0.5	<0.01	1	1	0.5	<0.01	0	0	0.0	0.00
Pacific Golden-Plover	*Pluvialis fulva*	1	1	0.5	0.00	0	0	0.0	0.00	3	11	1.2	0.04
Ruddy Turnstone	*Arenaria interpres*	0	0	0.0	0.00	0	0	0.0	0.00	1	1	0.4	<0.01
Brown Noddy	*Anous stolidus*	0	0	0.0	0.00	0	0	0.0	0.00	1	1	0.4	<0.01
White Tern	*Gygis alba*	128	344	59.3	1.59	22	52	10.2	0.24	122	322	48.0	1.27
Island Collared-Dove	*Streptopelia bitorquata*	51	66	23.6	0.31	136	256	63.0	1.19	79	116	31.1	0.46
White-throated Ground-Dove	*Gallicolumba xanthonura*	13	16	6.0	0.07	23	23	10.6	0.11	64	82	25.2	0.32
Mariana Fruit-Dove	*Ptilinopus roseicapilla*	189	623	87.5	2.88	150	240	69.4	1.11	212	462	83.4	1.82
Collared Kingfisher	*Todiramphus chloris*	150	294	69.4	1.36	124	285	57.4	1.32	190	374	74.8	1.47
Micronesian Honeyeater	*Myzomela rubratra*	131	236	60.6	1.09	60	96	27.8	0.44	87	125	34.3	0.49
Tinian Monarch	*Monarcha takatsukasae*	187	539	86.6	2.50	173	500	80.1	2.31	178	361	70.1	1.42
Rufous Fantail	*Rhipidura rufifrons*	202	786	93.5	3.64	188	502	87.0	2.32	235	686	92.5	2.70
Bridled White-eye	*Zosterops saypani*	216	2,222	100.0	10.29	216	1,770	100.0	8.19	253	2,024	99.6	7.97
Micronesian Starling	*Aplonis opaca*	177	513	81.9	2.38	106	226	49.1	1.05	215	614	84.7	2.42
Eurasian Tree Sparrow	*Passer montanus*	1	1	0.5	<0.01	3	13	1.4	0.06	13	62	5.1	0.24

Table 2. Population density and abundance estimates for native and alien Tinian land birds from three point-transect surveys. Data from Engbring *et al.* (1986) transects only. First row: mean density (birds/km^2 ± SE, with 95% CI). Second row: bird abundance (sum of density by habitat type times the area of habitat types) with 95% CI. Agriculture, coastal, and urban/residential habitat types were dropped for calculating bird abundance due to small sample size.

Species	1982	1996	2008
Yellow Bittern	1.5 ± 0.89 (0.5–4.4)	7.4 ± 2.49 (3.9–14.1)	18.2 ± 4.56 (11.2–29.6)
	127 (30–550)	764 (270–2,302)	1,695 (835–3,575)
White Tern	144.1 ± 17.24 (113.9–182.2)	25.3 ± 7.01 (14.8–43.2)	169.9 ± 19.66 (135.4–213.2)
	13,980 (9,349–21,512)	2,846 (1,121–7,300)	15,147 (10,067–23,041)
Island Collared-Dove	12.4 ± 2.04 (9.0–17.1)	34.3 ± 3.67 (27.8–42.3)	23.9 ± 3.24 (18.4–31.2)
	1,093 (642–2,024)	3,291 (2,296–4,777)	2,198 (1,374–3,648)
White-throated Ground-Dove	4.1 ± 1.45 (2.0–8.0)	4.6 ± 1.30 (2.7–8.0)	20.2 ± 3.91 (13.8–29.5)
	434 (136–1,421)	440 (174–1,147)	1,827 (1,045–3,226)
Mariana Fruit-Dove	42.6 ± 2.64 (37.7–48.1)	15.8 ± 1.23 (13.6–18.4)	33.1 ± 1.96 (29.4–37.1)
	3,909 (3,185–4,826)	1,539 (1,155–2,065)	3,029 (2,506–3,677)
Collared Kingfisher	7.0 ± 1.46 (4.7–10.5)	22.9 ± 3.28 (17.3–30.3)	61.3 ± 4.33 (53.3–70.4)
	570 (305–1,130)	2,268 (1,329–3,883)	5,439 (4,212–7,090)
Micronesian Honeyeater	77.2 ± 6.79 (64.9–91.7)	31.2 ± 4.26 (23.9–40.8)	41.3 ± 4.86 (32.8–52.0)
	7,859 (5,877–10,700)	2,847 (1,684–4,838)	3,716 (2,458–5,667)
Tinian Monarch	634.5 ± 37.88 (564.3–713.4)	705.7 ± 43.96 (624.3–797.6)	431.3 ± 30.75 (374.9–496.2)
	60,898 (49,484–75,398)	62,863 (50,476–78,758)	38,449 (29,992–49,849)
Rufous Fantail	641.2 ± 39.30 (568.4–723.3)	766.3 ± 40.85 (690.1–851.0)	975.0 ± 48.26 (884.6–1,074.6)
	58,336 (48,119–71,134)	67,191 (55,510–82,000)	86,112 (72,786–102,594)
Bridled White-eye	3,190.9 ± 101.79 (2,996.8–3,397.6)	2,731.9 ± 81.96 (2,575.5–2,897.8)	2,997.2 ± 105.80 (2,795.8–3,213.0)
	302,477 (270,218–338,821)	253,407 (225,258–286,044)	270,785 (239,579–306,772)
Micronesian Starling	133.9 ± 13.53 (109.8–163.3)	125.1 ± 13.34 (101.5–154.2)	349.5 ± 22.47 (308.0–396.6)
	11,543 (7,994–17,041)	10,841 (7,270–16,296)	30,088 (23,633–38,565)
Eurasian Tree Sparrow	2.1 ± 2.07 (0.4–10.7)	26.7 ± 16.42 (8.7–81.5)	110.2 ± 40.54 (54.7–222.2)
	155 (29–817)	1,244 (232–6,662)	2,111 (429–10,666)

Table 3. Repeated measures analysis of variance results for trends in Tinian land bird densities among years. Data from Engbring *et al.* (1986) transects only, excluding stations from agriculture, coastal, and urban/residential habitat types. Trends are denoted as increasing (▲), decreasing (▼), or stable (▬). Significant changes are marked in bold. Degrees of freedom for the differences of least squares means (Diff LSM) are 398.

		Fixed Effects		Diff LSM								
				82-96			82-08			96-08		
Species	Trend	$F_{2,398}$	*p*	Est (SE)	*t*	Adj-*p*	Est (SE)	*t*	Adj-*p*	Est (SE)	*t*	Adj-*p*
Yellow Bittern	▲	13.57	<0.001	-0.04 (0.02)	-1.86	0.153	-0.10 (0.02)	-5.14	<0.001	-0.07 (0.02)	-3.29	0.003
White Tern	▬	43.18	<0.001	0.47 (0.06)	7.55	<0.001	-0.06 (0.06)	-0.91	0.634	-0.53 (0.06)	-8.46	<0.001
Island Collared-Dove	▲	16.22	<0.001	-0.14 (0.03)	-5.66	<0.001	-0.09 (0.03)	-3.38	0.002	0.06 (0.03)	2.28	0.060
White-throated Ground-Dove	▲	27.87	<0.001	<0.01 (0.02)	-0.42	0.906	-0.12 (0.02)	-6.67	<0.001	-0.11 (0.02)	-6.24	<0.001
Mariana Fruit-Dove	▼	64.54	<0.001	0.19 (0.02)	10.92	<0.001	0.05 (0.02)	2.73	0.018	-0.14 (0.02)	-8.19	<0.001
Collared Kingfisher	▲	87.05	<0.001	-0.11 (0.03)	-3.79	<0.001	-0.36 (0.03)	-12.84	<0.001	-0.26 (0.03)	-9.05	<0.001
Micronesian Honeyeater	▼	31.76	<0.001	0.27 (0.04)	7.59	<0.001	0.20 (0.04)	5.90	<0.001	-0.06 (0.04)	-1.69	0.209
Tinian Monarch	▼	10.65	<0.001	-0.09 (0.09)	-0.97	0.597	0.31 (0.09)	3.42	0.002	0.40 (0.09)	4.39	<0.001
Rufous Fantail	▲	19.55	<0.001	-0.24 (0.09)	-2.75	0.017	-0.54 (0.09)	-6.24	<0.001	-0.30 (0.09)	-3.49	0.002
Bridled White-eye	▬	5.26	0.006	0.16 (0.05)	3.24	0.004	0.07 (0.05)	1.42	0.330	-0.09 (0.05)	-1.81	0.166
Micronesian Starling	▲	67.87	<0.001	0.04 (0.07)	0.57	0.836	-0.64 (0.07)	-9.79	<0.001	-0.68 (0.07)	-10.36	<0.001
Eurasian Tree Sparrow	▬	0.96	0.384	-0.02 (0.02)	-0.78	0.713	-0.03 (0.02)	-1.38	0.352	-0.01 (0.02)	-0.60	0.822

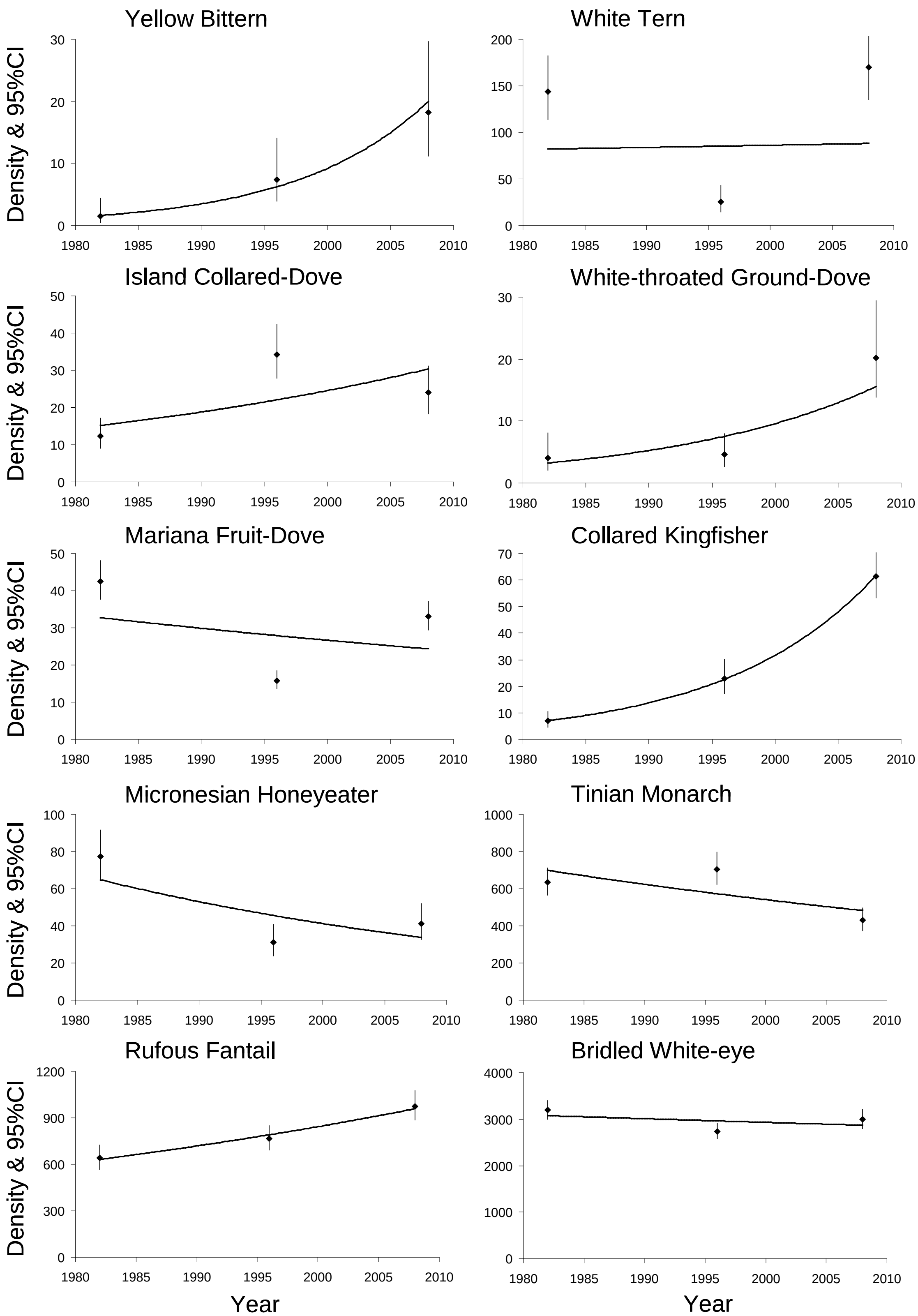

Figure 3. Density estimates (birds/km^2 and 95% CI) for native and alien Tinian land birds from three point-transect surveys (1982, 1996, and 2008). Densities were fitted with a line from an exponential model to illustrate population trends.

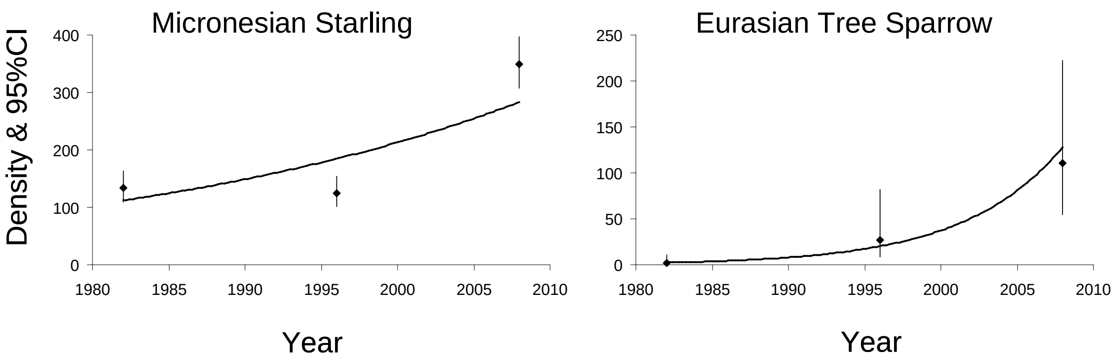

Figure 3. Continued.

Only five birds—White-throated Ground-Dove, Mariana Fruit-Dove, Tinian Monarch, Rufous Fantail, and Bridled White-eye—showed significant differences among regions by year (Table 4, Appendix 2). Between 1982 and 2008, White-throated Ground-Dove densities increased in the Diablo and Hagoi regions, and Rufous Fantail densities increased in the Carolinas and Masalog regions (Figure 4). Mariana Fruit-Dove densities declined in the Carolinas, and Tinian Monarch and Bridled White-eye densities declined in the Diablo region. In addition, densities of three birds—White Tern, Micronesian Honeyeater, and Micronesian Starling—differed by year and region but the year-region interaction was not significant (Table 4, Figure 4, Appendix 2). White Tern densities were greater in Diablo than in Hagoi, but densities in those regions were not different from densities in Carolinas and Masalog. Densities of Micronesian Honeyeater were greater in the Carolinas and Diablo regions than in the Hagoi and Masalog regions. Micronesian Starling densities were lower in Masalog than in the other regions.

Table 4. Repeated measures analysis of variance results for year, region, and year-region interaction fixed effects in Tinian land bird densities. Data from Engbring *et al.* (1986) transects only. Dash indicates interaction test not conducted because one or both main effects results were non-significant. Differences of least squares means for the significant fixed effects (bold for interaction, italics for region) are presented in Appendix 2 and summarized in Figure 3.

	Fixed Effects					
	Year		Region		Interaction	
Species	$F_{2,392}$	P	$F_{3,196}$	P	$F_{6,392}$	P
Yellow Bittern	10.17	<0.001	0.20	0.899	—	—
White Tern	40.78	<0.001	4.15	0.007	1.71	0.116
Island Collared-Dove	19.67	<0.001	1.47	0.224	—	—
White-throated Ground-Dove	16.98	<0.001	5.19	0.002	6.60	<0.001
Mariana Fruit-Dove	66.10	<0.001	5.99	<0.001	3.76	0.001
Collared Kingfisher	81.67	<0.001	2.17	0.093	—	—
Micronesian Honeyeater	25.99	<0.001	10.89	<0.001	1.73	0.113
Tinian Monarch	8.94	<0.001	7.61	<0.001	3.10	0.006
Rufous Fantail	28.31	<0.001	5.23	0.002	6.63	<0.001
Bridled White-eye	9.29	<0.001	6.04	<0.001	11.58	<0.001
Micronesian Starling	62.05	<0.001	3.60	0.014	1.43	0.200
Eurasian Tree Sparrow	1.29	0.276	1.36	0.256	—	—

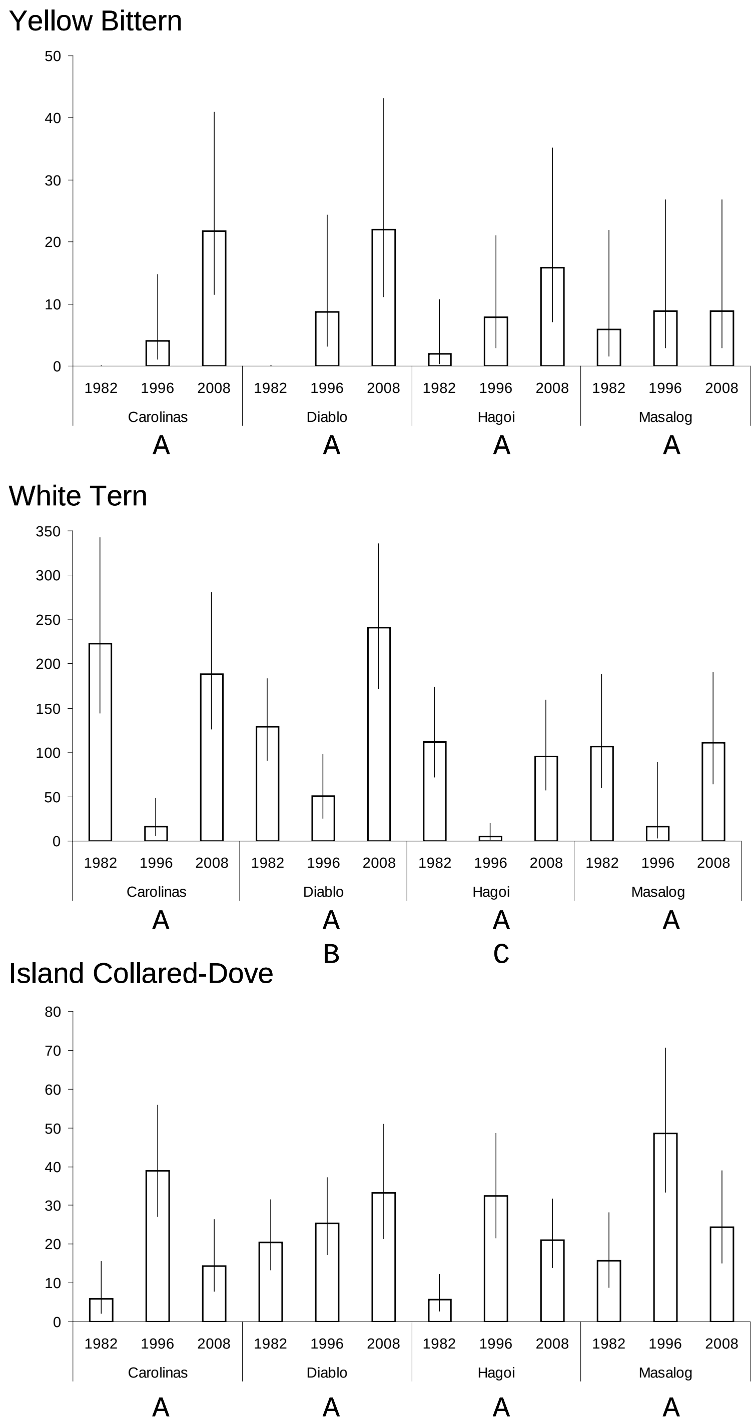

Figure 4. Density estimates (birds/km^2 and 95% CI) for native and alien Tinian land birds by region and year from three point-transect surveys (1982, 1996, and 2008). Differences of least squares means were assessed with repeated measures ANOVA (see Appendix 2 for details). Comparisons that share the same letter are not significantly different at the 0.05 level, adjusted for multiple comparisons. Comparisons below species name are year within region results (i.e., significant year, region and interaction effects), whereas comparisons below x-axis indicate fixed effects results (i.e., region or interaction effects were not significant).

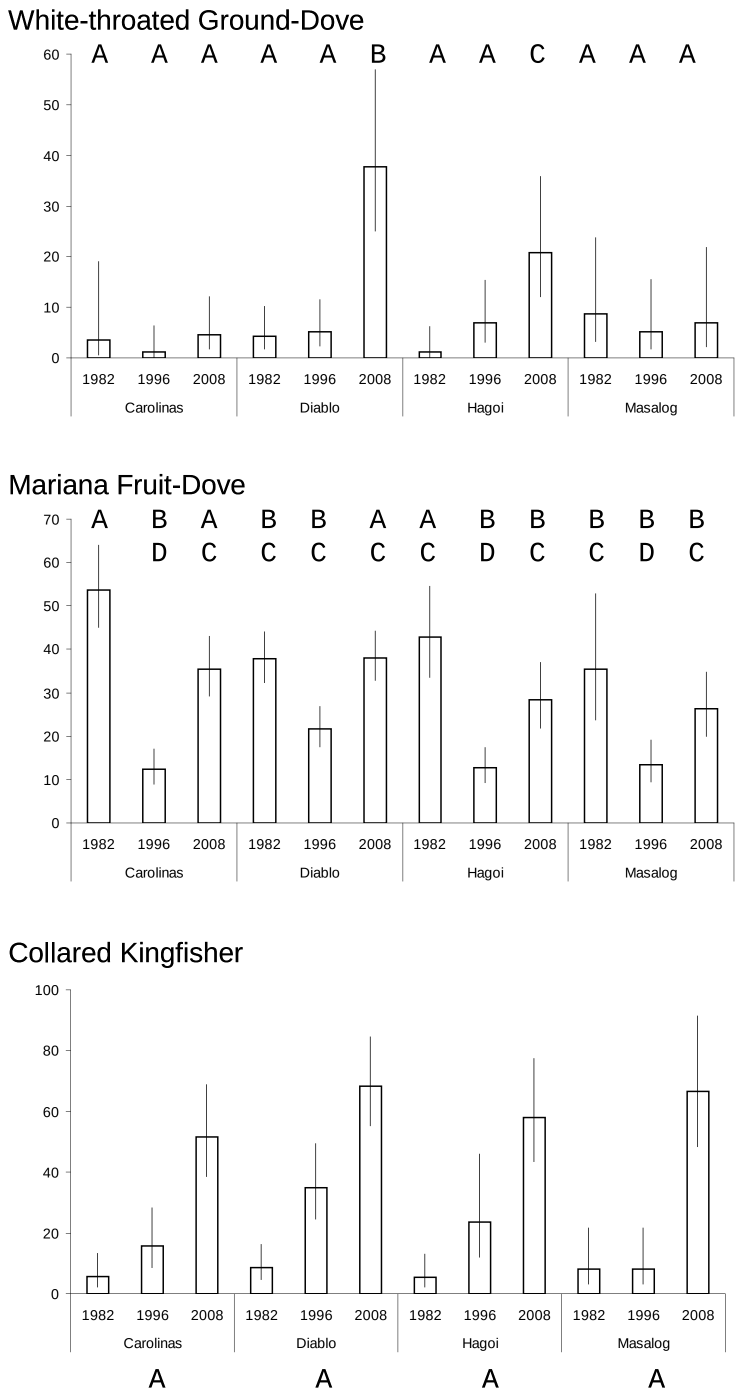

Figure 4. Continued.

Tinian Monarch densities have declined both temporally (survey year comparisons) and spatially (regional comparisons). We also tested for differences in Tinian Monarch densities among the different habitat types. Tinian Monarchs were found in all habitat types, but their densities were not distributed evenly among the habitats (Figure 5). Based on the 2008 survey, the greatest monarch densities were observed in limestone forest, secondary forest, and tangantangan thicket. The smallest densities were found in open field and urban/residential habitats. Monarch densities in limestone and secondary forests

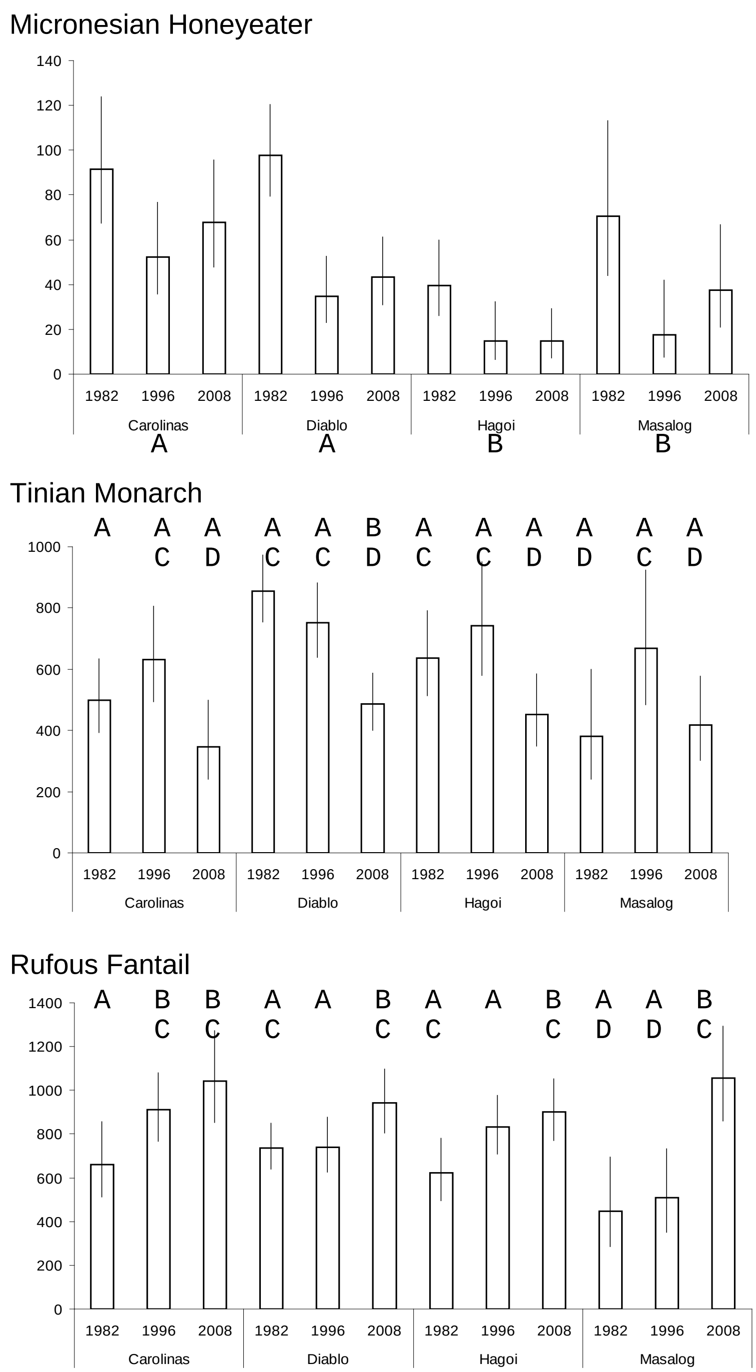

Figure 4. Continued.

were greater than those in open field and urban/residential habitat but not different from densities in tangantangan thicket (Table 5, Appendix 3).

We used the coefficient of variation (CV = SE/density) to evaluate Tinian Monarch estimator certainty by comparing the variability in densities calculated with and without the newly established transects. During the 2008 survey, 37 stations were sampled on four new transects. All of the stations were in limestone forest habitat; except for two stations on transect 13 that were located in tangantangan thicket habitat. Both of these habitats contain high densities of Tinian Monarch (Table 5). Incorporating the new transects

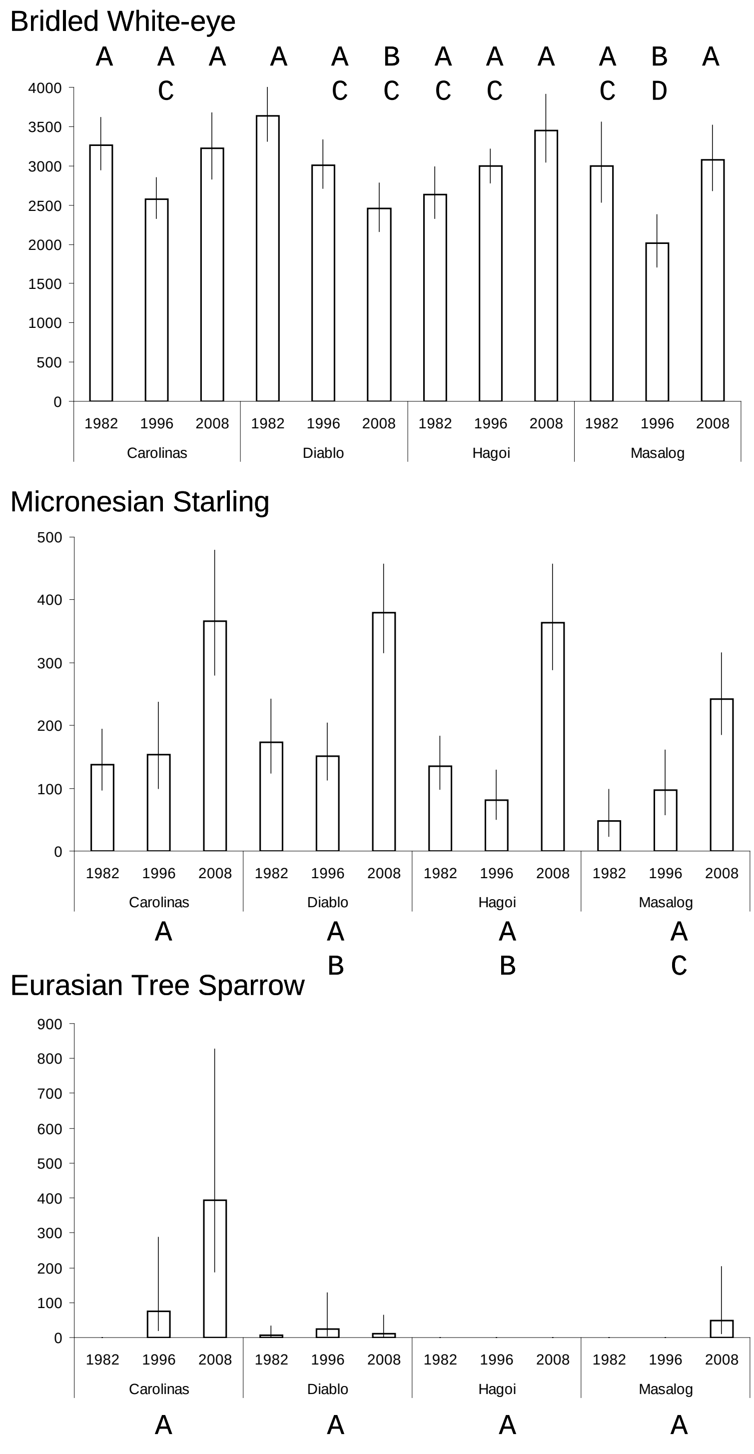

Figure 4. Continued**.**

increased the precision of monarch estimates in limestone forest habitat by more than 50% compared to estimates from just the original transects (Table 6). Sampling the new transects helped to improve precision in monarch densities by 15% in the Carolinas and Diablo regions, and most of the improvement was in estimates from the Carolinas Region. Overall, the precision of the island-wide monarch estimate was increased by almost 9%.

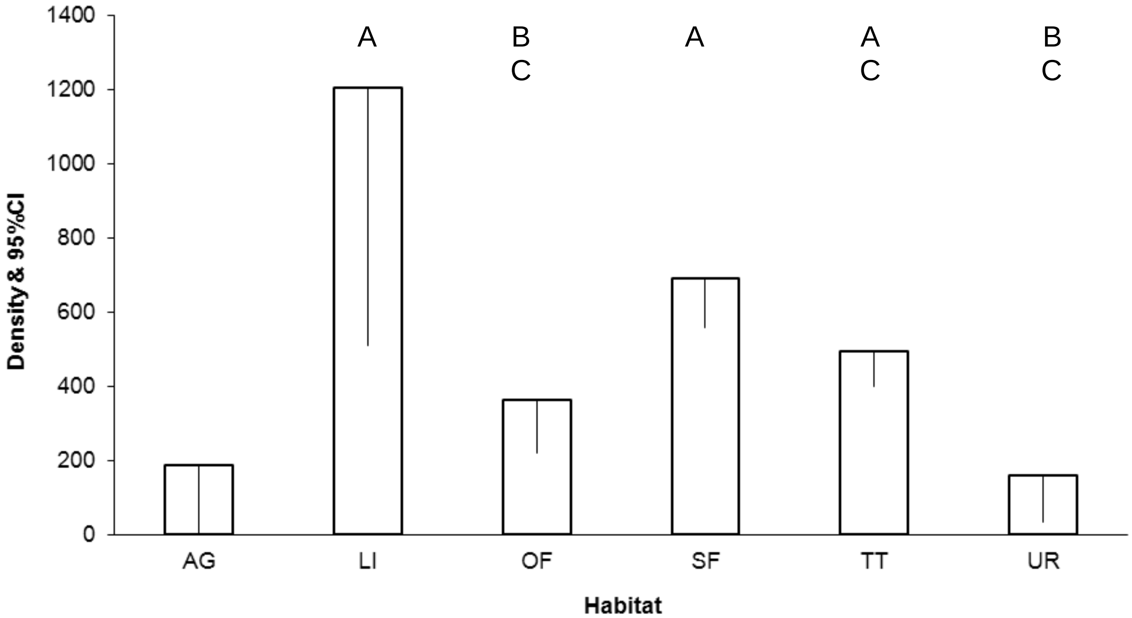

Figure 5. Density estimates (birds/km^2 and lower 95% CI) for the Tinian Monarch from all 14 transects sampled during the 2008 point-transect survey (data from all 14 transects). Habitat types are AG–agriculture, LI–limestone forest, OF–open field, SF–secondary forest, TT–tangantangan thicket, and UR–urban/residential. Differences of least squares means were assessed with a one-way ANOVA. Agriculture habitat was dropped from this analysis and coastal habitat was not sampled in 2008 (see Methods). Comparisons that share the same letter are not significantly different at the 0.05 level, adjusted for multiple comparisons.

Aguiguan

A total of 19 species was detected on the Aguiguan surveys (Table 7). Sufficient numbers of individuals were detected to calculate density and abundance estimates for nine native and one alien species. Bridled White-eye was the most abundant bird at over 44,000 birds on the 7 km^2 island, and Collared Kingfisher and Island Collared-Dove were the least abundant birds (Table 8). Densities for seven of the nine native birds—White-throated Ground-Dove, Mariana Fruit-Dove, Collared Kingfisher, Rufous Fantail, Bridled White-eye, Golden White-eye, and Micronesian Starling—were significantly greater in 2008 than 1982 (Table 8, Figure 6). No differences in densities were detected between the two surveys for White Tern and Micronesian Honeyeater. Densities of the alien Island Collared-Dove had increased significantly between 1982 and 2008.

Trends across islands

Densities have increased or remained stable for 84% (21 of 25 populations) of the nine native land bird species shared between Saipan (Camp *et al*. 2009) and one or both of the islands covered in this study (Table 9). White-throated Ground-Dove and Micronesian Starling populations increased on all three islands. Yellow Bittern, Collared Kingfisher, and Bridled White-eye populations either increased or remained stable. Change in the status of the Mariana Fruit-Dove, Micronesian Honeyeater, Rufous Fantail, and Golden White-eye populations was mixed among the islands.

Table 5. One-way ANOVA and multiple comparisons results of Tinian Monarch densities by habitat types from the 2008 survey (all 14 transects). Agriculture habitat type was dropped from the analysis due to small sample size. Significance was assessed at the alpha 0.05 level using Tukey's adjustment for multiple comparisons with 247 degrees of freedom (highlighted in bold). Habitat codes: LI–limestone forest; OF–open field; SF–secondary forest; TT–tangantangan thicket; and UR–urban/residential.

Fixed Effect	Num DF	Den DF	*F* Value	Pr > *F*	
Habitat	4	247	6.24	<0.001	
Habitat	Habitat	Estimate	Error	*t* Value	Adj *P*
LI	**OF**	0.76	0.203	3.75	**0.002**
LI	SF	0.01	0.173	0.04	1.000
LI	TT	0.31	0.165	1.85	0.348
LI	**UR**	1.11	0.382	2.91	**0.032**
OF	**SF**	-0.75	0.194	-3.89	**0.001**
OF	TT	-0.46	0.187	-2.43	0.111
OF	UR	0.35	0.392	0.89	0.900
SF	TT	0.30	0.154	1.94	0.298
SF	**UR**	1.10	0.377	2.93	**0.030**
TT	UR	0.80	0.374	2.15	0.201

Table 6. Measures of precision in Tinian Monarch 2008 densities for newly established transects, the original transects, the original transects in the same regions, and transects in limestone forest habitat [1].

Group	Density	SE	CV	Increased Precision
Original & New Transects	4.87	0.316	6.48	
Original Transects	4.51	0.32	7.09	8.6%
Limestone Forest Original & New Transects	6.41	0.735	11.48	
Limestone Forest Original Transects	4.97	1.152	23.20	50.5%
Carolinas & Diablo Regions Original & New Transects	5.03	0.392	7.80	
Carolinas & Diablo Regions Original Transects	4.46	0.409	9.18	15.0%
Carolinas Region Original & New Transects	3.73	0.544	14.56	
Carolinas Region Original Transects	3.62	0.661	18.23	20.1%
Diablo Region Original & New Transects	6.07	0.507	8.36	
Diablo Region Original Transects	5.07	0.488	9.62	13.1%

[1] New transects include 35 stations located in limestone forest and 2 stations in tangantangan thicket habitats and were pooled for this analysis.

Table 7. List of birds detected from the 1982 and 2008 point-transect surveys on Aguiguan. In 1982, 66 stations were sampled on 4 transects (88 counts; several stations were counted more than once), and in 2008, 80 stations were sampled in 5 transects. The number of stations occupied (Stns Ocpd), birds detected (# Dect), indices of percent occurrence (% Occ), and birds per station (BPS) were calculated. Nomenclature generally follows the AOU checklist and Reichel and Glass (1991) with updates. Density estimates were produced for birds in bold. Scientific names are provided in footnotes for select species.

	1982				2008			
Species	# Stns Ocpd	# Dect	% Occ	BPS	# Stns Ocpd	# Dect	% Occ	BPS
Micronesian Megapode	8	14	9.1	0.16	11	15	13.8	0.19
White-tailed Tropicbird	1	1	1.1	0.01	—	—	—	—
Red-tailed Tropicbird [1]	8	13	9.1	0.15	—	—	—	—
Great Frigatebird [2]	1	2	1.1	0.02	—	—	—	—
Yellow Bittern	1	1	1.1	0.01	—	—	—	—
Brown Noddy	14	20	15.9	0.23	—	—	—	—
Black Noddy [3]	31	75	35.2	0.85	1	1	1.2	0.01
White Tern	54	218	61.4	2.48	34	84	42.5	1.05
Sooty Tern [4]	1	1	1.1	0.01	—	—	—	—
Island Collared-Dove	9	16	10.2	0.18	28	50	35	0.63
White-throated Ground-Dove	10	18	11.4	0.20	25	37	31.2	0.46
Mariana Fruit-Dove	87	757	98.9	8.60	75	240	93.8	3.00
Guam Swiftlet	26	157	29.6	1.78	9	27	11.2	0.34
Collared Kingfisher	56	154	63.6	1.75	53	101	66.2	1.26
Micronesian Honeyeater	87	745	98.9	8.47	74	174	92.5	2.18
Rufous Fantail	84	453	95.5	5.15	77	219	96.2	2.74
Golden White-eye	83	444	94.3	5.05	74	268	92.5	3.35
Bridled White-eye	88	823	100.0	9.35	77	758	96.2	9.48
Micronesian Starling	71	207	80.7	2.35	69	167	86.2	2.09

[1] = *Phaethon rubricauda*
[2] = *Fregata minor*
[3] = *Anous minutus*
[4] = *Onychoprion fuscatus*

Discussion

Island trends

Abundances of half of the 10 native birds on Tinian—Yellow Bittern, White-throated Ground-Dove, Collared Kingfisher, Rufous Fantail, and Micronesian Starling—and seven of nine native birds on Aguiguan—White-throated Ground-Dove, Mariana Fruit-Dove, Collared Kingfisher, Rufous Fantail,

Table 8. Population density and abundance estimates for native and alien Aguiguan land birds from two point-transect surveys (1982 and 2008). First row: mean density (birds/km^2 ± SE, with 95% CI). Second row: 2008 bird abundance (density by habitat times the habitat area) with 95% CI. Significance was assessed at the alpha 0.05 level using two-sample *z*-test (in bold). Change was defined as increasing (▲), decreasing (▼), or not significantly different (▬).

Species	1982	2008	*z* Value	*P*	Change
White Tern	169.6 ± 27.0 (124.2–231.6)	218.8 ± 44.2 (147.3–325.1)	-0.95	0.341	▬
		1,214 (604–3,651)			
Island Collared-Dove	4.4 ± 1.8 (2.0–9.7)	66.9 ± 16.7 (41.1–108.8)	-3.72	<0.001	▲
		307 (151–658)			
White-throated Ground-Dove	13.1 ± 4.8 (6.6–26.3)	100.2 ± 26.5 (59.9–167.6)	-3.23	0.001	▲
		484 (260–953)			
Mariana Fruit-Dove	107.5 ± 6.5 (95.4–121.1)	141.0 ± 10.8 (121.3–164.0)	-2.67	0.008	▲
		818 (604–1,170)			
Collared Kingfisher	13.1 ± 2.0 (9.7–17.8)	50.3 ± 6.6 (38.9–65.0)	-5.39	<0.001	▲
		347 (184–1,186)			
Micronesian Honeyeater	368.3 ± 19.6 (331.8–408.7)	336.2 ± 27.1 (286.7–394.1)	-0.96	0.337	▬
		2,128 (1,564–3,046)			
Rufous Fantail	568.8 ± 39.6 (496.0–652.2)	1.157.9 ± 89.3 (995.0–1,347.5)	-6.41	<0.001	▲
		6,429 (4,765–13,666)			
Golden White-eye	529.1 ± 40.6 (455.1–615.2)	1,292.6 ± 111.9 (1,089.7–1,533.4)	-6.41	<0.001	▲
		7,496 (4,983–17,387)			
Bridled White-eye	1,685.6 ± 102.3 (1,495.7–1,899.6)	6,771.2 ± 490.2 (5,867.6–7,814.1)	-10.15	<0.001	▲
		44,293 (32,246–63,031)			
Micronesian Starling	86.5 ± 10.9 (67.6–110.7)	505.2 ± 52.7 (411.5–620.3)	-7.78	<0.001	▲
		3,531 (1,902–12,374)			

Bridled White-eye, Golden White-eye, and Micronesian Starling—have increased since the 1982 survey. In addition, three native birds on both islands have remained stable—White Tern on both islands, Bridled White-eye on Tinian, and Micronesian Honeyeater on Aguiguan. Large increases in densities of Yellow Bittern, Rufous Fantail, and Micronesian Starling on Tinian, and Rufous Fantail on Aguiguan support increasing their status classification. Changes in the other birds were not sufficient to warrant reclassification. Reichel and Glass (1991) listed Yellow Bittern

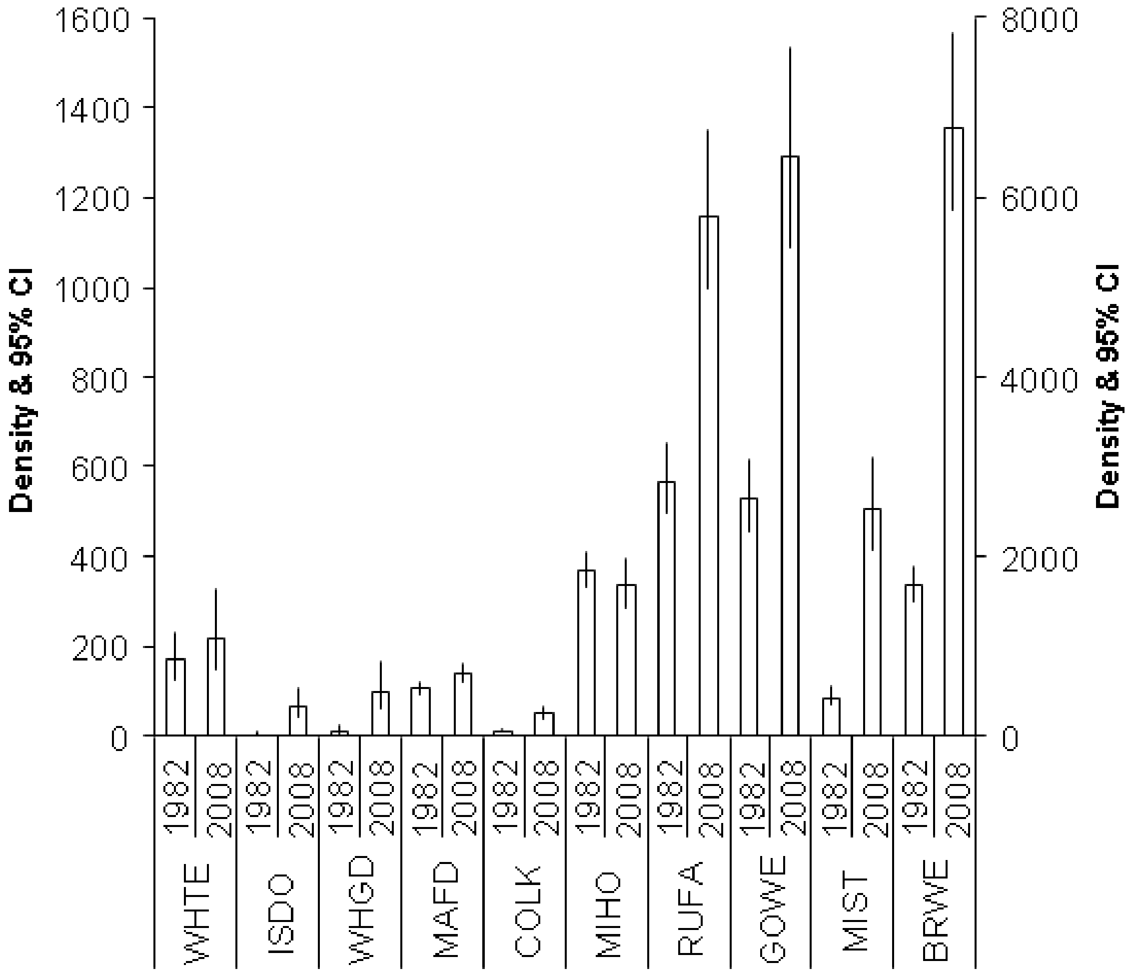

Figure 6. Density estimates (birds/km ^{2} and 95% CI) for native and alien Aguiguan land birds from two point-transect surveys (1982 and 2008). The primary y-axis is for the first nine species, and the secondary y-axis is for Bridled White-eye. Species codes are WHTE–White Tern; ISDO–Island Collared-Dove; WHGD–White-throated Ground-Dove; MAFD–Mariana Fruit-Dove; COLK–Collared Kingfisher; MIHO–Micronesian Honeyeater; RUFA–Rufous Fantail; GOWE–Golden White-eye; MIST–Micronesian Starling; and BRWE–Bridled White-eye.

as rare, and now, at more than 1,600 birds, the species can be considered uncommon—observing them in representative habitat is not certain but likely. Rufous Fantail and Micronesian Starling on Tinian may be considered abundant. Abundances of about 86,000 and 30,000 birds, respectively, make finding them in large numbers within representative habitat a certainty. Likewise, Rufous Fantail on Aguiguan may be considered abundant at more than 6,400 birds. Alien birds—Island Collared-Dove and Eurasian Tree Sparrow—densities increased on both islands and Tinian, respectively, and both species may be categorized as common or abundant.

No species had declined on Aguiguan, whereas Mariana Fruit-Dove, Micronesian Honeyeater, and Tinian Monarch declined on Tinian. Relatively large numbers of these birds remain on Tinian (> 3,000 individuals), and changes to their abundance status are unwarranted. However, declines for these native species are a concern, especially for the Tinian Monarch, which is endemic to Tinian and listed as threatened by the CNMI and vulnerable by the IUCN. Likely causes for these declines include predation

Table 9. Comparison of density (birds/km^2 and 95% confidence intervals) and change in the status of nine native land bird populations from the most recent point-transect surveys (Tinian and Aguiguan 2008, Saipan 2007) by island. A "—" denotes the species was not detected on the island. Changes are denoted as increasing (▲), decreasing (▼), or stable (▬). Results for Saipan are from Camp *et al*. (2009).

	Tinian		Aguiguan		Saipan	
Species	Density (95% CI)	Change	Density (95% CI)	Change	Density (95% CI)	Change
Yellow Bittern	18.2 (11.2–29.6)	▲	—		11.4 (4.8–21.2)	▲
White-Throated Ground-Dove	20.2 (13.8–29.5)	▲	100.2 (59.9–167.6)	▲	100.5 (77.1–127.9)	▲
Mariana Fruit-Dove	33.1 (29.4–37.1)	▼	141.0 (121.3–164.0)	▲	65.5 (53.0–79.8)	▬
Collared Kingfisher	61.3 (53.3–70.4)	▲	50.3 (38.9–65.0)	▲	25.8 (16.8–39.1)	▬
Micronesian Honeyeater	41.3 (32.8–52.0)	▼	336.2 (286.7–394.1)	▬	482.3 (383.5–651.5)	▲
Rufous Fantail	975.0 (884.6–1,074.6)	▲	1,157.9 (995.0–1,347.5)	▲	469.1 (394–1,601.5)	▼
Golden White-Eye	—		1,292.6 (1,089.7–1,533.4)	▲	711.8 (534.8–975.3)	▼
Bridled White-eye	2,997.2 (2,795.8–3,213.0)	▬	6,771.2 (5,867.6–7,814.1)	▲	4,713.3 (3,982.7–5,488.9)	▬
Micronesian Starling	349.5 (308.0–396.6)	▲	505.2 (411.5–620.3)	▲	161.9 (96.8–257.5)	▲

and habitat loss/degradation. One possible explanation for increases in Aguiguan birds has been extensive expansion of secondary forest and brush habitats. About half of the island was cleared for agriculture during the 1930s and 1940s, and those fallow fields are now dominated by *Lantana camara* and other alien plants and secondary forest (Figure 7). Forests currently cover about 70% of the island, and an additional 20% of the island is occupied primarily by *L. camara* fields, providing habitat for birds.

Trends across islands

The U.S. Fish and Wildlife Service conducted a land bird survey on Saipan in 2007 and assessed population trends (Camp *et al*. 2009). Comparing trends among the neighboring Mariana Islands of Tinian, Aguiguan, and Saipan provides an index of the species' regional trends. The carnivorous birds—Yellow Bittern and Collared Kingfisher—increased or remained stable. Densities of Yellow Bittern have increased on Tinian and Saipan, but the species is found in very low numbers on Aguiguan. In fact, no birds were detected on counts during the 2008 Aguiguan survey, although one was seen along a transect (APM, pers. obs.), and only one bird was detected during the 1982 survey. Yellow Bittern inhabit swamps, marshes, and other grassy habitats, and secondary forest, and bittern may be absent from Aguiguan because very little grass-dominated habitat now occurs on this island. In contrast, bittern may be increasing on Tinian and Saipan where grassy and open habitats have increased.

Trends among the fruit-eating birds—White-throated Ground-Dove and Mariana Fruit-Dove—were mixed, and the pattern does not appear to correspond to increases in human populations. Micronesian Starling, a largely frugivorous species, increased on all three islands. Camp *et al*.

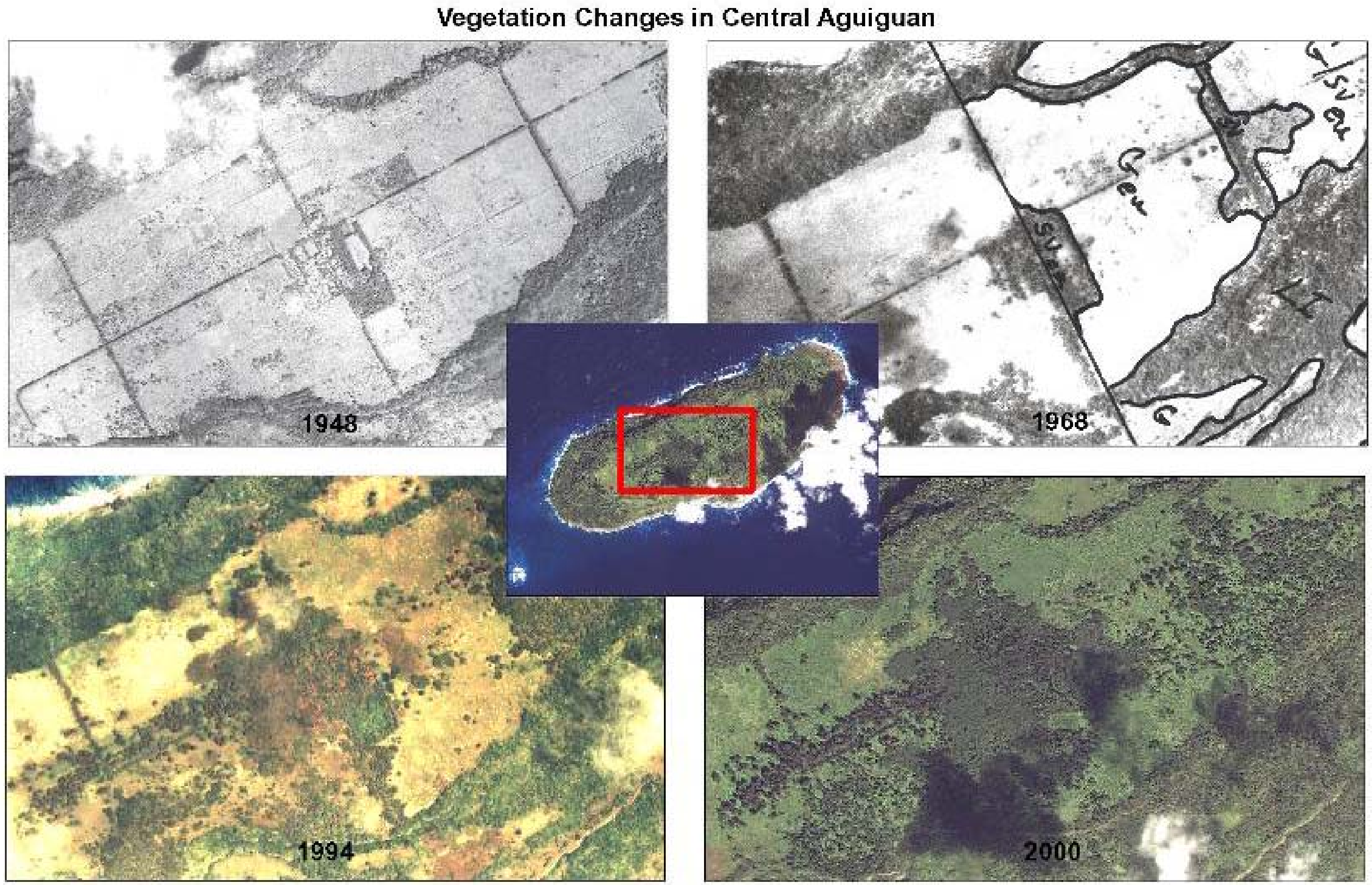

Figure 7. Vegetation changes in central Aguiguan, as shown by a series of aerial photos of the center of the island. About half of the island was cleared for agriculture during the 1930s and 1940s (represented in the 1948 photo). Agriculture halted after WWII, and the fallow fields were dominated by grass (labeled G in the 1964 photo, and represented in yellow in the 1994 photo). Secondary forest expanded into the fallow fields and is represented in dark green in the bottom two photos. By 2000, the non-native shrub *Lantana camara* had replaced the grass in the fallow fields, and is represented in light green in the 2000 photo. One of the few remaining patches of grass is visible in the 2000 photo (just below the right corner of the central panel).

(2009) speculated that fruit-eating birds on Saipan may have benefited from the expansion of scarlet gourd (*Coccinia grandis*). This alien, smothering vine also occurs on Tinian but only locally and has not formed dense canopies. Scarlet gourd is not reported from Aguiguan. Thus, it is likely that scarlet gourd does not account for much of the increases in the fruit-eating bird populations on Tinian and Aguiguan. Another explanation is that there may be different patterns of hunting across the islands that account for the mixed trends. For example, people have traditionally hunted White-throated Ground-Dove and Mariana Fruit-Dove; it is not legal to hunt these doves, but current hunting prevalence is unknown.

The insectivorous Rufous Fantail increased on Tinian and Aguiguan but decreased on the more densely human-populated Saipan. Trends for birds with diets including insects, nectar, and fruits were mixed. The Aguiguan population of Bridled White-eye may have increased in response to expansion of secondary forest and lantana field habitats. Habitat change and increased human populations may not be strong enough drivers to affect Bridled White-eye populations on Saipan and Tinian. Golden White-eye is known from the recent fossil record to have formerly occurred on Tinian, where it is now extinct (Craig 1999). The species was detected in large numbers on Aguiguan, and the population there has more than doubled (529 to 1,293 birds/km^2) between 1982 and 2008. Craig (1996, as cited in Craig 1999) estimated Golden White-eye densities on Saipan at about 1,200 birds/km^2, an estimate that roughly matches the 1997 point-transect density (Camp *et al*. 2009). The current Golden White-eye densities on Aguiguan were almost twice that reported from Saipan (1,300 and 700 birds/km^2, respectively), and their trends were in opposite directions—increasing on Aguiguan and decreasing on Saipan (Camp *et al*. 2009).

The Golden White-eye decline on Saipan may be a result of increasing human populations and habitat loss/degradation, whereas these factors are not affecting the population on uninhabited Aguiguan. Generally, the birds on Tinian, Aguiguan, and Saipan are doing comparatively well for insular species. This is surprising given that nearly all of the native forests on Tinian and Saipan have been lost and that all habitats on Aguiguan suffer from heavy browsing by feral goats, and forest regeneration is thus severely selective. Recent surveys on Rota showed that seven of eight bird trends have declined (Amar *et al*. 2008). The only bird to increase on Rota was the Micronesian Starling, which has also increased on the other three islands. Similar to our findings, Amar *et al*. concluded that the loss of forests or the spread of scarlet gourd does not fully explain bird population trends on Rota. Likewise, large-scale climate change, increases in human populations on Rota, Saipan, and Tinian, and Malathion insecticide spraying do not appear to be consistent drivers of bird trends. The status of brown tree snake on Rota, Tinian, and Aguiguan is unknown, but reports of sightings are very rare. Brown tree snakes have been frequently sighted on Saipan (Rodda and Savidge 2007). However, declines in the bird populations do not follow the geographic pattern of snakes spreading across an island, as they did on Guam (Savidge 1987). Further research is needed to identify the causative agents of population change in these four islands.

Rare species and those not appropriate for point-transect sampling

Three native land birds—Micronesian Megapode, Guam Swiftlet, and Nightingale Reed-Warbler—were either not detected during the point-transect counts or the numbers of birds detected were too few to estimate densities. Point-transect methods may not be appropriate for the very rare megapode and reed-warbler, and the behavior of the swiftlet violates modeling assumptions. A remnant population of a few Micronesian Megapode may persist on Tinian (Wiles *et al*. 1987, U.S. Fish and Wildlife Service 1998a), although no individuals were detected during any of the three point-transect surveys. Wiles *et al*. (1987) speculated that the megapode population on Tinian may originate from birds being brought in by humans or possibly dispersing from nearby populations on Aguiguan or Saipan. Aguiguan supports a small Micronesian Megapode population (U.S. Fish and Wildlife Service 1998a), and about equal numbers of birds were detected during the 1982 and 2008 surveys (14 and 15 birds, respectively). During the 1982 survey on Aguiguan, four Nightingale Reed-Warbler incidental sightings were recorded, but not during the eight-minute counts (Engbring *et al*. 1986). The reed-warbler has not been observed on Aguiguan since the mid-1990s and may be extirpated on Aguiguan (U.S. Fish and Wildlife Service 1998b, Esselstyn *et al*. 2003). The Nightingale Reed-Warbler was not detected by the 2008 survey, neither during counts nor incidentally. The Guam Swiftlet historically occurred on Tinian but is extinct on the island (U.S. Fish and Wildlife Service 1991, Cruz *et al*. 2008); no swiftlets were detected during the three point-transect surveys. Cruz *et al*. (2008) noted that the Aguiguan swiftlet population has probably remained fairly stable between 1987 and 2002; however, it is notable that the numbers of birds detected in 2008 were only 17% of those detected in 1982 (27 and 157 birds, respectively). This apparent decline was further supported by the drop in numbers of birds detected at roosting cave counts between 1985 and 1997–2002 (Cruz *et al*. 2008).

The 1996 White Tern estimate on Tinian was markedly lower than from the other surveys. It is likely that the low tern estimate was an artifact of when the survey was conducted and not an actual change in the tern population. The original survey in 1982 and the most recent 2008 survey occurred early in the year and early in the breeding season (although terns can breed in all months of the year; Niethammer and Patrick-Castilaw 1998), whereas the 1996 survey was conducted in late August and after the breeding season. When not nesting, most individuals spend extended periods at sea (Niethammer and Patrick-Castilaw 1998); therefore portions of the population in 1996 were outside the sampling frame. In addition, the 1996 survey focused on passerines, and not all tern detections may have been recorded (F. Amidon, pers. comm.).

Tinian Monarch concerns

Lusk *et al*. (2000) calculated the 1996 Tinian Monarch abundance at about 55,700 birds, which is 11% less than our estimate of 62,900 birds. This change is due to differences between the analytical procedures. For example, Lusk *et al*. (2000) did not extrapolate densities to abundance for 2,375 ha of open fields, although monarchs were detected in this habitat. After dropping densities from the open fields and adjusting for this area difference, our densities resulted in 48,424 birds, an estimate that fell within their 95% CI. This difference is easily accounted for in differences between our methods, specifically differences in the model selected and advances within program DISTANCE. Lusk *et al*. (2000) calculated their density estimate from a half-normal model with polynomial adjustments and an effective detection radius (EDR) of just over 34 m. We estimated the EDR at 30.18 m from a hazard-rate detection function (without adjustments) and incorporating observers as a covariate, where the smaller EDR resulted in greater densities. Lastly, Lusk *et al*. (2000) used program VCPADJ (Fancy 1997) and a previous version of DISTANCE (Laake *et al*. 1994) to standardize the survey conditions and estimate densities. The updated version of DISTANCE (Thomas *et al*. 2006) we used incorporates all of the modeling in one program and uses an improved technique to account for differences in sampling conditions (Thomas *et al*. 2006, Marques *et al*. 2007).

Estimator certainty usually declines with decreasing density estimates; however, this pattern was not observed for the 2008 Tinian Monarch estimate. There was an almost three-fold decrease in estimator certainty for the 2008 estimate than that observed for either the 1982 or 1996 estimates. Variability in monarch densities on the new transects was substantially less than that observed on the entire set of original transects and the subset of original transects within the same regions. In the two regions where additional transects were sampled—Carolinas and Diablo—variability in the Tinian Monarch density diverged (see Appendix 2). Variability in the monarch density in the Diablo region remained low even though densities declined. In contrast, uncertainty increased four-fold in the Carolinas region. The additional stations sampled during the 2008 survey in the Carolinas region reduced variability to the Tinian Monarch estimate, but estimator certainty was poorer than in previous surveys. Adding stations to the limestone forest habitat improved estimator certainty by 50%. Thus, additional stations may be needed to further improve estimator certainty. Allocation of stations for monitoring Tinian Monarch should consider additional sampling in habitats with uncertain estimates including agriculture (CV > 100%), urban/residential (CV = 69%), and lastly in open field habitat where 23% CV is adequate for trends monitoring. Also, additional sampling could be allocated in the Carolinas region to help reduce the almost 50% CV.

The U.S. Fish and Wildlife Service (2005) post-delisting plan for the Tinian Monarch identified the loss of habitat as a primary threat. The USFWS identified limestone and secondary forests and tangantangan thicket as quality habitat for the monarch (densities of 30.7, 7.7, and 6.0 birds/ha, respectively). Monarch densities in 2008 declined dramatically by 79% in limestone forests and substantially by 24% and 27% in secondary forest and tangantangan thicket, respectively, from those reported by U.S. Fish and Wildlife Service (2005). We also show that the monarch population declined over the 27-year period, and the decline between 1996 and 2008 may be attributed to reduced bird density in open field habitat. Continued monitoring of the Tinian Monarch will be necessary to track its long-term survival, especially when the species is faced with population declines, threats such as the potential invasion of the brown tree snake, and habitat lost to the increasing development of Tinian Island.

Bird monitoring for conservation on Tinian

The current status of the brown tree snake on Tinian is unknown, but there have been several reports of snakes from Tinian and other CNMI islands (Colvin *et al*. 2005). Interdiction measures to prevent the introduction and establishment of snakes are crucial for the survival of CNMI land birds. If established, the brown tree snake will decimate the avifauna (Savidge 1987, Wiles *et al*. 2003). Military operations are likely to increase traffic between Guam and Tinian, increasing the probability of transporting brown tree snake to Tinian.

Military operations are likely to result in increases in the human population and land use conversion, which will expand human-dominated habitats. Between 1980 and 2000, the human population on Tinian increased 309% from 866 to 3,540 people, respectively (CNMI Department of Commerce 2001). Human increases were concentrated in and around the main settlement, San Jose, and not in the northern two-thirds of the island leased by the military. Humans have predominantly increased in the Carolinas region (which includes much of San Jose), where both alien birds and four native birds—Yellow Bittern, Collared Kingfisher, Rufous Fantail, and Micronesian Starling—increased. In contrast, Tinian Monarch, a native bird typically associated with forests, especially limestone forests, declined in the Carolinas region where housing, roads, and services have expanded. These bird trend patterns could well continue or be exacerbated by increasing military actions.

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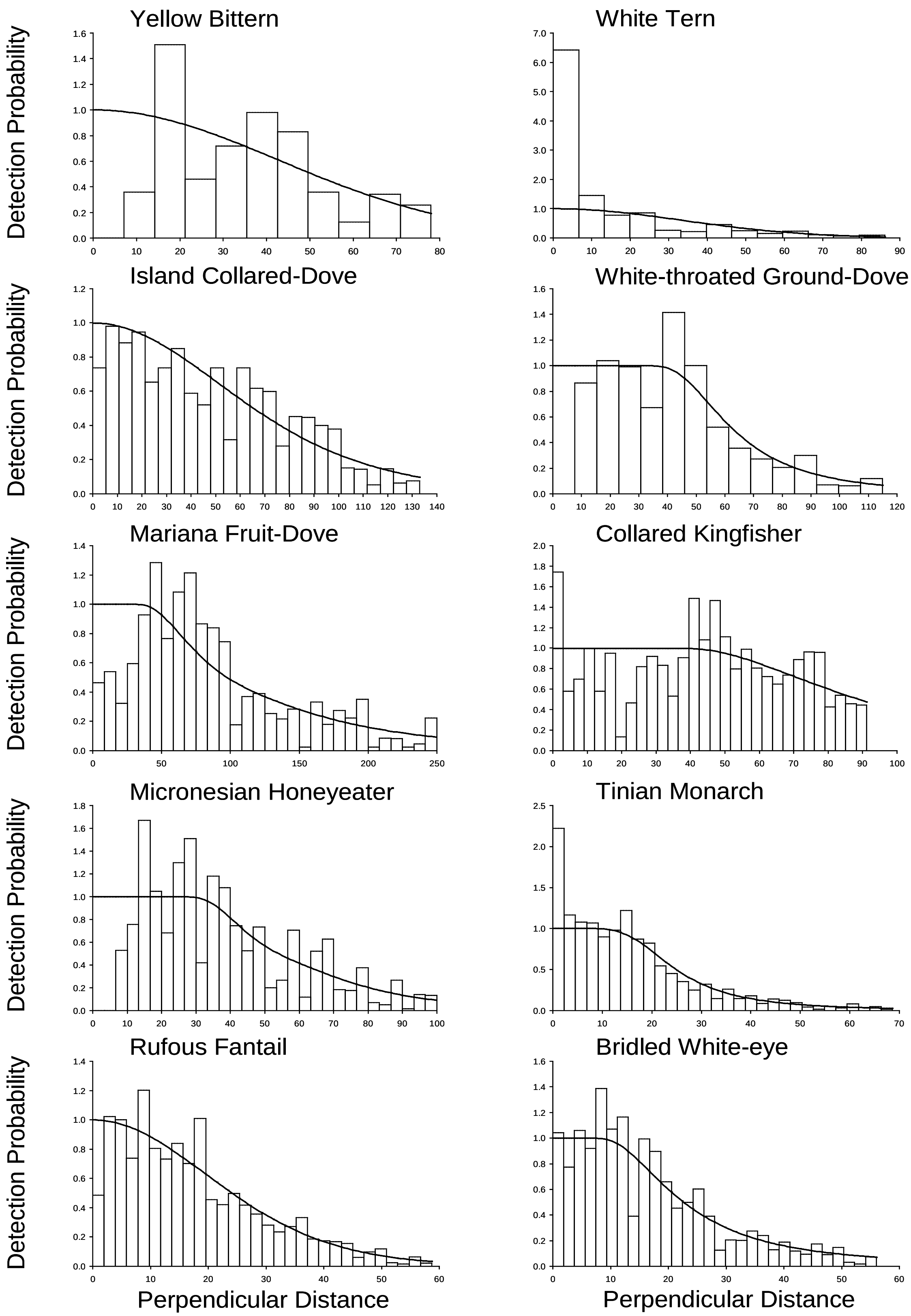
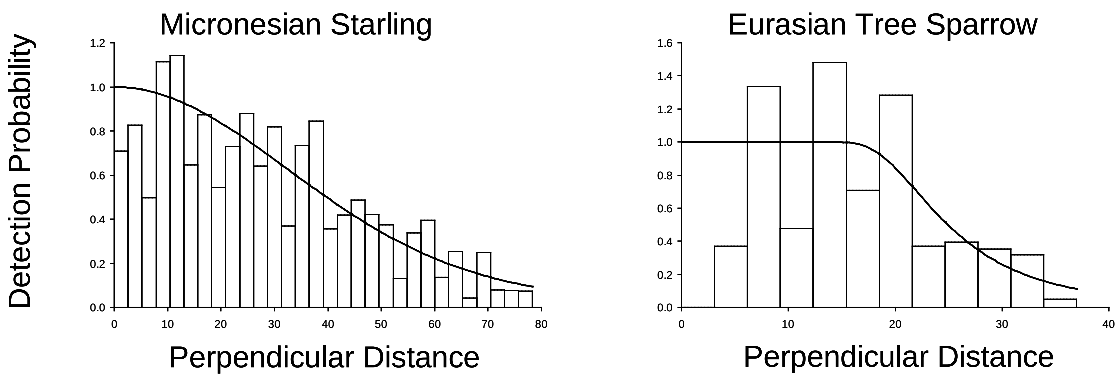
Appendix 1. Species data and models

Appendix 1, Table 10. Detection function parameters used to derive population densities for each species on Tinian.

Species	Truncation	Key Model	Adjustment Terms	Covariates
Yellow Bittern	78.0	Half normal	None	None
White Tern	92.7	Half normal	None	None
Island Collared-Dove	133.0	Half normal	None	Observer
White-throated Ground-Dove	115.0	Hazard rate	None	None
Mariana Fruit-Dove	250.0	Hazard rate	None	Observer
Collared Kingfisher	91.2	Hazard rate	None	Observer
Micronesian Honeyeater	100.0	Hazard rate	None	Year
Tinian Monarch	68.6	Hazard rate	None	Observer
Rufous Fantail	58.7	Half normal	None	Observer
Bridled White-eye	56.0	Hazard rate	None	Observer
Micronesian Starling	78.3	Half normal	None	Observer
Eurasian Tree Sparrow	37.0	Hazard rate	None	None



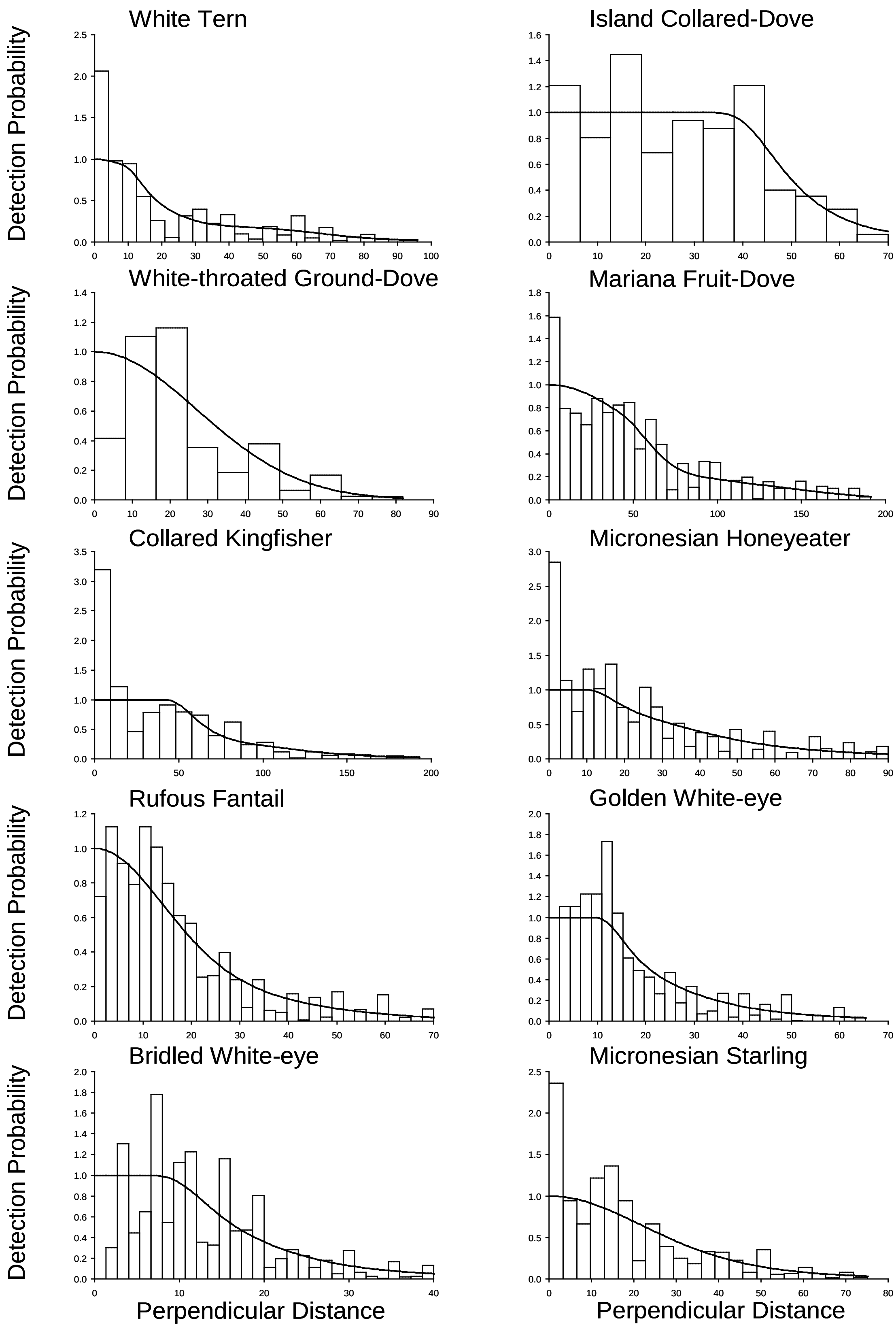
Appendix 1, Figure 8. Histograms of bird detections used to calculate population estimates on Tinian. The best fit lines for these data were modeled with program DISTANCE.



Appendix 1, Figure 8. Continued.

Appendix 1, Table 11. Detection function parameters used to derive population densities for each species on Aguiguan.

Species	Truncation	Key Model	Adjustment Terms	Covariates
White Tern	95.8	Half normal	Cosine (2,3)	Observer
Island Collared-Dove	70.0	Hazard rate	None	None
White-throated Ground-Dove	81.8	Half normal	None	None
Mariana Fruit-Dove	191.0	Hazard rate	Cosine (2)	Observer
Collared Kingfisher	193.0	Hazard rate	None	Year
Micronesian Honeyeater	90.0	Hazard rate	None	Observer
Rufous Fantail	70.0	Hazard rate	None	Observer
Golden White-eye	65.3	Hazard rate	None	Observer
Bridled White-eye	40.0	Hazard rate	None	Cloud
Micronesian Starling	75.1	Half normal	None	Observer



Appendix 1, Figure 9. Histograms of bird detections used to calculate population estimates on Aguiguan. The best fit lines for these data were modeled with program DISTANCE.

Appendix 2. Results from region and year analyses for Tinian land birds

Appendix 2, Table 12. Density estimates (birds/km^2), standard error (SE), and 95% confidence intervals (Lower and Upper 95% CI) by region and year.

Yellow Bittern Region	Year	Estimate	SE	L 95% CI	U 95% CI
Carolinas	1982	0.0	0.00	0.0	0.0
	1996	4.0	2.92	1.1	14.8
	2008	21.8	7.10	11.6	40.9
Diablo	1982	0.0	0.00	0.0	0.0
	1996	8.8	4.81	3.2	24.3
	2008	22.0	7.69	11.2	43.1
Hagoi	1982	2.0	2.01	0.4	10.7
	1996	7.9	4.10	3.0	21.0
	2008	15.8	6.59	7.1	35.1
Masalog	1982	5.9	4.27	1.6	21.9
	1996	8.9	5.25	3.0	26.8
	2008	8.9	5.25	3.0	26.8

White Tern Region	Year	Estimate	SE	L 95% CI	U 95% CI
Carolinas	1982	222.6	48.36	144.7	342.2
	1996	16.7	9.48	5.8	48.2
	2008	188.4	37.91	126.4	280.7
Diablo	1982	129.3	22.75	91.3	183.0
	1996	50.5	17.20	26.1	97.7
	2008	240.4	40.57	172.2	335.5
Hagoi	1982	112.0	24.79	72.2	173.5
	1996	5.5	3.83	1.5	19.4
	2008	95.6	24.72	57.4	159.1
Masalog	1982	106.5	30.64	60.1	188.6
	1996	16.4	16.40	3.0	88.9
	2008	110.6	29.96	64.5	189.7

Island Collared-Dove Region	Year	Estimate	SE	L 95% CI	U 95% CI
Carolinas	1982	5.8	3.01	2.2	15.4
	1996	38.8	7.08	27.0	55.7
	2008	14.3	4.45	7.8	26.3
Diablo	1982	20.4	4.48	13.3	31.4
	1996	25.4	4.91	17.3	37.1
	2008	33.1	7.27	21.5	51.0
Hagoi	1982	5.7	2.24	2.7	12.2
	1996	32.4	6.65	21.6	48.6
	2008	21.0	4.34	13.9	31.6
Masalog	1982	15.7	4.58	8.8	28.0
	1996	48.6	9.06	33.5	70.6
	2008	24.3	5.75	15.1	39.0

White-throated Ground-Dove

Region	Year	Estimate	SE	L 95% CI	U 95% CI
Carolinas	1982	3.5	3.58	0.7	19.0
	1996	1.2	1.19	0.2	6.3
	2008	4.6	2.35	1.8	12.0
Diablo	1982	4.3	1.96	1.8	10.2
	1996	5.1	2.15	2.3	11.4
	2008	37.7	7.94	25.0	56.9
Hagoi	1982	1.2	1.17	0.2	6.2
	1996	7.0	2.88	3.1	15.4
	2008	20.9	5.79	12.1	35.8
Masalog	1982	8.7	4.60	3.2	23.7
	1996	5.2	3.02	1.8	15.5
	2008	7.0	4.27	2.2	21.8

Mariana Fruit-Dove

Region	Year	Estimate	SE	L 95% CI	U 95% CI
Carolinas	1982	53.7	4.72	45.1	64.0
	1996	12.4	1.98	9.0	17.0
	2008	35.4	3.44	29.2	43.0
Diablo	1982	37.8	2.94	32.4	44.1
	1996	21.7	2.32	17.6	26.9
	2008	38.0	2.85	32.8	44.1
Hagoi	1982	42.8	5.19	33.6	54.5
	1996	12.8	1.99	9.4	17.4
	2008	28.4	3.77	21.8	37.0
Masalog	1982	35.4	7.04	23.8	52.8
	1996	13.4	2.33	9.5	19.0
	2008	26.3	3.64	19.9	34.8

Collared Kingfisher

Region	Year	Estimate	SE	L 95% CI	U 95% CI
Carolinas	1982	5.5	2.52	2.3	13.2
	1996	15.7	4.72	8.7	28.3
	2008	51.6	7.47	38.7	68.9
Diablo	1982	8.7	2.76	4.7	16.1
	1996	34.8	6.13	24.6	49.3
	2008	68.3	7.33	55.2	84.5
Hagoi	1982	5.4	2.48	2.3	13.0
	1996	23.5	8.07	12.1	45.9
	2008	57.9	8.41	43.4	77.4
Masalog	1982	8.1	4.14	3.1	21.5
	1996	8.1	4.14	3.1	21.5
	2008	66.5	10.47	48.5	91.4

Micronesian Honeyeater

Region	Year	Estimate	SE	L 95% CI	U 95% CI
Carolinas	1982	91.3	14.03	67.3	123.9
	1996	52.4	10.06	35.8	76.7
	2008	67.6	11.77	47.8	95.5
Diablo	1982	97.8	10.21	79.6	120.3
	1996	34.8	7.26	23.1	52.5
	2008	43.5	7.52	30.9	61.2
Hagoi	1982	39.7	8.25	26.3	59.9
	1996	14.7	6.00	6.7	32.3
	2008	14.7	5.21	7.4	29.3
Masalog	1982	70.5	16.66	44.0	113.1
	1996	17.6	7.86	7.4	41.8
	2008	37.5	10.85	21.1	66.6

Tinian Monarch

Region	Year	Estimate	SE	L 95% CI	U 95% CI
Carolinas	1982	498.2	59.84	392.1	633.1
	1996	630.7	77.83	493.1	806.7
	2008	346.6	63.26	241.2	498.1
Diablo	1982	856.3	55.40	753.3	973.3
	1996	750.9	61.05	639.1	882.3
	2008	485.4	46.84	400.8	587.8
Hagoi	1982	637.6	69.30	513.3	791.9
	1996	742.8	92.48	579.6	952.0
	2008	451.9	58.83	348.6	585.7
Masalog	1982	380.7	86.11	242.0	598.9
	1996	668.5	107.43	483.8	923.8
	2008	417.8	66.85	302.8	576.5

Rufous Fantail

Region	Year	Estimate	SE	L 95% CI	U 95% CI
Carolinas	1982	661.9	85.71	511.2	857.0
	1996	910.1	78.08	766.9	1079.9
	2008	1042.1	104.31	853.5	1272.4
Diablo	1982	735.8	52.83	638.1	848.5
	1996	740.8	63.56	624.8	878.4
	2008	941.1	73.59	805.8	1099.0
Hagoi	1982	622.5	70.41	496.8	780.2
	1996	832.3	66.17	710.3	975.4
	2008	900.0	70.38	770.1	1051.7
Masalog	1982	446.6	98.39	287.2	694.6
	1996	507.5	93.23	350.8	734.3
	2008	1055.6	106.93	860.5	1295.0

Bridled White-eye

Region	Year	Estimate	SE	L 95% CI	U 95% CI
Carolinas	1982	3266.8	167.26	2949.0	3618.8
	1996	2575.7	129.82	2328.6	2849.1
	2008	3226.9	210.72	2831.7	3677.1
Diablo	1982	3638.8	174.30	3308.4	4002.1
	1996	3005.3	155.07	2712.0	3330.2
	2008	2452.9	153.80	2165.2	2778.8
Hagoi	1982	2637.7	162.75	2331.4	2984.2
	1996	2993.9	108.38	2785.5	3218.0
	2008	3452.9	216.50	3045.8	3914.5
Masalog	1982	3000.8	251.17	2533.1	3554.7
	1996	2014.2	165.16	1706.3	2377.6
	2008	3072.7	204.33	2686.2	3514.8

Micronesian Starling

Region	Year	Estimate	SE	L 95% CI	U 95% CI
Carolinas	1982	137.1	23.93	96.9	194.0
	1996	153.5	33.59	99.5	236.8
	2008	365.9	49.47	279.5	479.1
Diablo	1982	173.2	29.13	124.2	241.5
	1996	151.3	22.61	112.5	203.4
	2008	380.2	35.28	316.3	456.9
Hagoi	1982	134.5	20.97	98.6	183.5
	1996	80.7	19.21	50.4	129.2
	2008	363.2	42.03	288.4	457.5
Masalog	1982	48.4	17.42	23.9	98.3
	1996	96.9	24.71	58.2	161.2
	2008	242.2	31.92	185.7	315.8

Eurasian Tree Sparrow

Region	Year	Estimate	SE	L 95% CI	U 95% CI
Carolinas	1982	0.0	0.00	0.0	0.0
	1996	75.2	56.71	19.6	288.4
	2008	393.8	151.68	187.6	826.7
Diablo	1982	6.1	6.13	1.1	32.3
	1996	24.3	24.53	4.6	129.1
	2008	12.1	12.27	2.3	64.5
Hagoi	1982	0.0	0.00	0.0	0.0
	1996	0.0	0.00	0.0	0.0
	2008	0.0	0.00	0.0	0.0
Masalog	1982	0.0	0.00	0.0	0.0
	1996	0.0	0.00	0.0	0.0
	2008	49.2	39.24	11.9	203.8

Appendix 2, Table 13. Comparison of densities by region and year using repeated measures ANOVA for eight species with significant main effects (Table 4). Effect codes are Yr–year, Reg–region, and Y*R–interaction between year and region main effects.

White Tern

Effect	Region	Year	Region	Year	Estimate	SE	DF	*t* Value	Adj *P*
Yr		1982		1996	0.4920	0.0649	392	7.58	<.001
Yr		1982		2008	-0.0298	0.0649	392	-0.46	0.890
Yr		1996		2008	-0.5218	0.0649	392	-8.04	<.001
Reg	Carolina		Diablo		-0.0054	0.0795	196	-0.07	1.000
Reg	Carolina		Hagoi		0.2214	0.0855	196	2.59	0.050
Reg	Carolina		Masalog		0.1707	0.0947	196	1.80	0.275
Reg	Diablo		Hagoi		0.2268	0.0749	196	3.03	0.015
Reg	Diablo		Masalog		0.1761	0.0852	196	2.07	0.168
Reg	Hagoi		Masalog		-0.0507	0.0909	196	-0.56	0.944

White-throated Ground-Dove

Effect	Region	Year	Region	Year	Estimate	SE	DF	*t* Value	Adj *P*
Yr		1982		1996	-0.0042	0.0181	392	-0.23	0.971
Yr		1982		2008	-0.0934	0.0181	392	-5.16	<.001
Yr		1996		2008	-0.0891	0.0181	392	-4.93	<.001
Reg	Carolina		Diablo		-0.0845	0.0225	196	-3.75	0.001
Reg	Carolina		Hagoi		-0.0433	0.0242	196	-1.79	0.282
Reg	Carolina		Masalog		-0.0264	0.0268	196	-0.98	0.759
Reg	Diablo		Hagoi		0.0412	0.0212	196	1.94	0.214
Reg	Diablo		Masalog		0.0581	0.0241	196	2.41	0.079
Reg	Hagoi		Masalog		0.0169	0.0257	196	0.66	0.913
Yr*Reg	Carolina	1982	Diablo	1982	-0.0081	0.0355	576	-0.23	1.000
Yr*Reg	Carolina	1982	Hagoi	1982	0.0156	0.0382	576	0.41	1.000
Yr*Reg	Carolina	1982	Masalog	1982	-0.0416	0.0423	576	-0.98	0.998
Yr*Reg	Carolina	1982	Carolina	1996	0.0136	0.0380	392	0.36	1.000
Yr*Reg	Carolina	1982	Diablo	1996	-0.0148	0.0355	576	-0.42	1.000
Yr*Reg	Carolina	1982	Hagoi	1996	-0.0320	0.0382	576	-0.84	1.000
Yr*Reg	Carolina	1982	Masalog	1996	-0.0177	0.0423	576	-0.42	1.000
Yr*Reg	Carolina	1982	Carolina	2008	-0.0211	0.0380	392	-0.56	1.000
Yr*Reg	Carolina	1982	Diablo	2008	-0.2381	0.0355	576	-6.70	<.001
Yr*Reg	Carolina	1982	Hagoi	2008	-0.1210	0.0382	576	-3.16	0.072
Yr*Reg	Carolina	1982	Masalog	2008	-0.0273	0.0423	576	-0.64	1.000
Yr*Reg	Diablo	1982	Hagoi	1982	0.0238	0.0335	576	0.71	1.000
Yr*Reg	Diablo	1982	Masalog	1982	-0.0335	0.0381	576	-0.88	0.999
Yr*Reg	Diablo	1982	Carolina	1996	0.0217	0.0355	576	0.61	1.000
Yr*Reg	Diablo	1982	Diablo	1996	-0.0067	0.0288	392	-0.23	1.000
Yr*Reg	Diablo	1982	Hagoi	1996	-0.0239	0.0335	576	-0.71	1.000
Yr*Reg	Diablo	1982	Masalog	1996	-0.0096	0.0381	576	-0.25	1.000
Yr*Reg	Diablo	1982	Carolina	2008	-0.0130	0.0355	576	-0.37	1.000
Yr*Reg	Diablo	1982	Diablo	2008	-0.2299	0.0288	392	-7.99	<.001
Yr*Reg	Diablo	1982	Hagoi	2008	-0.1129	0.0335	576	-3.37	0.039

Yr*Reg	Diablo	1982	Masalog	2008	-0.0192	0.0381	576	-0.50	1.000
Yr*Reg	Hagoi	1982	Masalog	1982	-0.0572	0.0406	576	-1.41	0.962
Yr*Reg	Hagoi	1982	Carolina	1996	-0.0020	0.0382	576	-0.05	1.000
Yr*Reg	Hagoi	1982	Diablo	1996	-0.0304	0.0335	576	-0.91	0.999
Yr*Reg	Hagoi	1982	Hagoi	1996	-0.0476	0.0345	392	-1.38	0.966
Yr*Reg	Hagoi	1982	Masalog	1996	-0.0334	0.0406	576	-0.82	1.000
Yr*Reg	Hagoi	1982	Carolina	2008	-0.0368	0.0382	576	-0.96	0.998
Yr*Reg	Hagoi	1982	Diablo	2008	-0.2537	0.0335	576	-7.57	<.001
Yr*Reg	Hagoi	1982	Hagoi	2008	-0.1366	0.0345	392	-3.97	0.005
Yr*Reg	Hagoi	1982	Masalog	2008	-0.0429	0.0406	576	-1.06	0.996
Yr*Reg	Masalog	1982	Carolina	1996	0.0552	0.0423	576	1.30	0.978
Yr*Reg	Masalog	1982	Diablo	1996	0.0268	0.0381	576	0.70	1.000
Yr*Reg	Masalog	1982	Hagoi	1996	0.0096	0.0406	576	0.24	1.000
Yr*Reg	Masalog	1982	Masalog	1996	0.0239	0.0422	392	0.57	1.000
Yr*Reg	Masalog	1982	Carolina	2008	0.0205	0.0423	576	0.48	1.000
Yr*Reg	Masalog	1982	Diablo	2008	-0.1965	0.0381	576	-5.16	<.001
Yr*Reg	Masalog	1982	Hagoi	2008	-0.0794	0.0406	576	-1.95	0.724
Yr*Reg	Masalog	1982	Masalog	2008	0.0143	0.0422	392	0.34	1.000
Yr*Reg	Carolina	1996	Diablo	1996	-0.0284	0.0355	576	-0.80	1.000
Yr*Reg	Carolina	1996	Hagoi	1996	-0.0456	0.0382	576	-1.19	0.989
Yr*Reg	Carolina	1996	Masalog	1996	-0.0313	0.0423	576	-0.74	1.000
Yr*Reg	Carolina	1996	Carolina	2008	-0.0347	0.0380	392	-0.91	0.999
Yr*Reg	Carolina	1996	Diablo	2008	-0.2517	0.0355	576	-7.08	<.001
Yr*Reg	Carolina	1996	Hagoi	2008	-0.1346	0.0382	576	-3.52	0.024
Yr*Reg	Carolina	1996	Masalog	2008	-0.0409	0.0423	576	-0.97	0.998
Yr*Reg	Diablo	1996	Hagoi	1996	-0.0172	0.0335	576	-0.51	1.000
Yr*Reg	Diablo	1996	Masalog	1996	-0.0029	0.0381	576	-0.08	1.000
Yr*Reg	Diablo	1996	Carolina	2008	-0.0063	0.0355	576	-0.18	1.000
Yr*Reg	Diablo	1996	Diablo	2008	-0.2233	0.0288	392	-7.75	<.001
Yr*Reg	Diablo	1996	Hagoi	2008	-0.1062	0.0335	576	-3.17	0.070
Yr*Reg	Diablo	1996	Masalog	2008	-0.0125	0.0381	576	-0.33	1.000
Yr*Reg	Hagoi	1996	Masalog	1996	0.0143	0.0406	576	0.35	1.000
Yr*Reg	Hagoi	1996	Carolina	2008	0.0109	0.0382	576	0.28	1.000
Yr*Reg	Hagoi	1996	Diablo	2008	-0.2061	0.0335	576	-6.15	<.001
Yr*Reg	Hagoi	1996	Hagoi	2008	-0.0890	0.0345	392	-2.58	0.293
Yr*Reg	Hagoi	1996	Masalog	2008	0.0047	0.0406	576	0.12	1.000
Yr*Reg	Masalog	1996	Carolina	2008	-0.0034	0.0423	576	-0.08	1.000
Yr*Reg	Masalog	1996	Diablo	2008	-0.2204	0.0381	576	-5.78	<.001
Yr*Reg	Masalog	1996	Hagoi	2008	-0.1033	0.0406	576	-2.54	0.317
Yr*Reg	Masalog	1996	Masalog	2008	-0.0096	0.0422	392	-0.23	1.000
Yr*Reg	Carolina	2008	Diablo	2008	-0.2170	0.0355	576	-6.10	<.001
Yr*Reg	Carolina	2008	Hagoi	2008	-0.0999	0.0382	576	-2.61	0.277
Yr*Reg	Carolina	2008	Masalog	2008	-0.0062	0.0423	576	-0.15	1.000
Yr*Reg	Diablo	2008	Hagoi	2008	0.1171	0.0335	576	3.50	0.026
Yr*Reg	Diablo	2008	Masalog	2008	0.2108	0.0381	576	5.53	<.001
Yr*Reg	Hagoi	2008	Masalog	2008	0.0937	0.0406	576	2.31	0.474

Mariana Fruit-Dove

Effect	Region	Year	Region	Year	Estimate	SE	DF	*t* Value	Adj *P*
Yr		1982		1996	0.1941	0.0175	392	11.11	<.001
Yr		1982		2008	0.0522	0.0175	392	2.99	0.008
Yr		1996		2008	-0.1418	0.0175	392	-8.12	<.001
Reg	Carolina		Diablo		0.0185	0.0214	196	0.86	0.824
Reg	Carolina		Hagoi		0.0551	0.0230	196	2.39	0.082
Reg	Carolina		Masalog		0.0965	0.0255	196	3.78	0.001
Reg	Diablo		Hagoi		0.0366	0.0202	196	1.82	0.269
Reg	Diablo		Masalog		0.0780	0.0230	196	3.40	0.005
Reg	Hagoi		Masalog		0.0414	0.0245	196	1.69	0.332
Yr*Reg	Carolina	1982	Diablo	1982	0.1129	0.0341	578	3.31	0.047
Yr*Reg	Carolina	1982	Hagoi	1982	0.0836	0.0367	578	2.28	0.495
Yr*Reg	Carolina	1982	Masalog	1982	0.1822	0.0406	578	4.48	0.001
Yr*Reg	Carolina	1982	Carolina	1996	0.3105	0.0367	392	8.47	<.001
Yr*Reg	Carolina	1982	Diablo	1996	0.2347	0.0341	578	6.88	<.001
Yr*Reg	Carolina	1982	Hagoi	1996	0.3066	0.0367	578	8.35	<.001
Yr*Reg	Carolina	1982	Masalog	1996	0.3030	0.0406	578	7.46	<.001
Yr*Reg	Carolina	1982	Carolina	2008	0.0922	0.0367	392	2.52	0.333
Yr*Reg	Carolina	1982	Diablo	2008	0.1105	0.0341	578	3.24	0.058
Yr*Reg	Carolina	1982	Hagoi	2008	0.1779	0.0367	578	4.85	0.000
Yr*Reg	Carolina	1982	Masalog	2008	0.2070	0.0406	578	5.09	<.001
Yr*Reg	Diablo	1982	Hagoi	1982	-0.0293	0.0322	578	-0.91	0.999
Yr*Reg	Diablo	1982	Masalog	1982	0.0693	0.0366	578	1.89	0.763
Yr*Reg	Diablo	1982	Carolina	1996	0.1976	0.0341	578	5.79	<.001
Yr*Reg	Diablo	1982	Diablo	1996	0.1218	0.0278	392	4.38	0.001
Yr*Reg	Diablo	1982	Hagoi	1996	0.1937	0.0322	578	6.03	<.001
Yr*Reg	Diablo	1982	Masalog	1996	0.1901	0.0366	578	5.20	<.001
Yr*Reg	Diablo	1982	Carolina	2008	-0.0207	0.0341	578	-0.61	1.000
Yr*Reg	Diablo	1982	Diablo	2008	-0.0024	0.0278	392	-0.08	1.000
Yr*Reg	Diablo	1982	Hagoi	2008	0.0650	0.0322	578	2.02	0.679
Yr*Reg	Diablo	1982	Masalog	2008	0.0941	0.0366	578	2.57	0.298
Yr*Reg	Hagoi	1982	Masalog	1982	0.0986	0.0390	578	2.53	0.326
Yr*Reg	Hagoi	1982	Carolina	1996	0.2270	0.0367	578	6.18	<.001
Yr*Reg	Hagoi	1982	Diablo	1996	0.1511	0.0322	578	4.70	0.000
Yr*Reg	Hagoi	1982	Hagoi	1996	0.2231	0.0333	392	6.71	<.001
Yr*Reg	Hagoi	1982	Masalog	1996	0.2194	0.0390	578	5.63	<.001
Yr*Reg	Hagoi	1982	Carolina	2008	0.0086	0.0367	578	0.23	1.000
Yr*Reg	Hagoi	1982	Diablo	2008	0.0270	0.0322	578	0.84	1.000
Yr*Reg	Hagoi	1982	Hagoi	2008	0.0943	0.0333	392	2.84	0.170
Yr*Reg	Hagoi	1982	Masalog	2008	0.1234	0.0390	578	3.17	0.072
Yr*Reg	Masalog	1982	Carolina	1996	0.1284	0.0406	578	3.16	0.073
Yr*Reg	Masalog	1982	Diablo	1996	0.0525	0.0366	578	1.44	0.956
Yr*Reg	Masalog	1982	Hagoi	1996	0.1245	0.0390	578	3.19	0.066
Yr*Reg	Masalog	1982	Masalog	1996	0.1208	0.0407	392	2.97	0.123
Yr*Reg	Masalog	1982	Carolina	2008	-0.0900	0.0406	578	-2.21	0.540
Yr*Reg	Masalog	1982	Diablo	2008	-0.0716	0.0366	578	-1.96	0.721

Yr*Reg	Masalog	1982	Hagoi	2008	-0.0043	0.0390	578	-0.11	1.000
Yr*Reg	Masalog	1982	Masalog	2008	0.0249	0.0407	392	0.61	1.000
Yr*Reg	Carolina	1996	Diablo	1996	-0.0758	0.0341	578	-2.22	0.534
Yr*Reg	Carolina	1996	Hagoi	1996	-0.0039	0.0367	578	-0.11	1.000
Yr*Reg	Carolina	1996	Masalog	1996	-0.0076	0.0406	578	-0.19	1.000
Yr*Reg	Carolina	1996	Carolina	2008	-0.2184	0.0367	392	-5.96	<.001
Yr*Reg	Carolina	1996	Diablo	2008	-0.2000	0.0341	578	-5.86	<.001
Yr*Reg	Carolina	1996	Hagoi	2008	-0.1327	0.0367	578	-3.61	0.018
Yr*Reg	Carolina	1996	Masalog	2008	-0.1035	0.0406	578	-2.55	0.314
Yr*Reg	Diablo	1996	Hagoi	1996	0.0719	0.0322	578	2.24	0.523
Yr*Reg	Diablo	1996	Masalog	1996	0.0683	0.0366	578	1.87	0.779
Yr*Reg	Diablo	1996	Carolina	2008	-0.1425	0.0341	578	-4.18	0.002
Yr*Reg	Diablo	1996	Diablo	2008	-0.1242	0.0278	392	-4.47	0.001
Yr*Reg	Diablo	1996	Hagoi	2008	-0.0568	0.0322	578	-1.77	0.834
Yr*Reg	Diablo	1996	Masalog	2008	-0.0277	0.0366	578	-0.76	1.000
Yr*Reg	Hagoi	1996	Masalog	1996	-0.0037	0.0390	578	-0.09	1.000
Yr*Reg	Hagoi	1996	Carolina	2008	-0.2145	0.0367	578	-5.84	<.001
Yr*Reg	Hagoi	1996	Diablo	2008	-0.1961	0.0322	578	-6.10	<.001
Yr*Reg	Hagoi	1996	Hagoi	2008	-0.1288	0.0333	392	-3.87	0.007
Yr*Reg	Hagoi	1996	Masalog	2008	-0.0996	0.0390	578	-2.55	0.310
Yr*Reg	Masalog	1996	Carolina	2008	-0.2108	0.0406	578	-5.19	<.001
Yr*Reg	Masalog	1996	Diablo	2008	-0.1924	0.0366	578	-5.26	<.001
Yr*Reg	Masalog	1996	Hagoi	2008	-0.1251	0.0390	578	-3.21	0.063
Yr*Reg	Masalog	1996	Masalog	2008	-0.0960	0.0407	392	-2.36	0.439
Yr*Reg	Carolina	2008	Diablo	2008	0.0184	0.0341	578	0.54	1.000
Yr*Reg	Carolina	2008	Hagoi	2008	0.0857	0.0367	578	2.33	0.454
Yr*Reg	Carolina	2008	Masalog	2008	0.1148	0.0406	578	2.83	0.173
Yr*Reg	Diablo	2008	Hagoi	2008	0.0673	0.0322	578	2.09	0.627
Yr*Reg	Diablo	2008	Masalog	2008	0.0965	0.0366	578	2.64	0.262
Yr*Reg	Hagoi	2008	Masalog	2008	0.0292	0.0390	578	0.75	1.000

Micronesian Honeyeater

Effect	Region	Year	Region	Year	Estimate	SE	DF	*t* Value	Adj *P*
Yr		1982		1996	0.2518	0.0363	392	6.94	<.001
Yr		1982		2008	0.1876	0.0363	392	5.17	<.001
Yr		1996		2008	-0.0642	0.0363	392	-1.77	0.182
Reg	Carolina		Diablo		0.0323	0.0478	196	0.68	0.906
Reg	Carolina		Hagoi		0.2413	0.0514	196	4.70	<.001
Reg	Carolina		Masalog		0.1799	0.0569	196	3.16	0.010
Reg	Diablo		Hagoi		0.2090	0.0450	196	4.64	<.001
Reg	Diablo		Masalog		0.1476	0.0512	196	2.88	0.023
Reg	Hagoi		Masalog		-0.0615	0.0546	196	-1.13	0.674

Tinian Monarch

Effect	Region	Year	Region	Year	Estimate	SE	DF	*t* Value	Adj *P*
Yr		1982		1996	-0.1750	0.0925	392	-1.89	0.143
Yr		1982		2008	0.2156	0.0925	392	2.33	0.053

Yr		1996		2008	0.3905	0.0925	392	4.22	<.001
Reg	Carolina		Diablo		-0.4019	0.1180	196	-3.40	0.004
Reg	Carolina		Hagoi		-0.2164	0.1270	196	-1.70	0.324
Reg	Carolina		Masalog		0.1388	0.1406	196	0.99	0.757
Reg	Diablo		Hagoi		0.1854	0.1112	196	1.67	0.344
Reg	Diablo		Masalog		0.5406	0.1265	196	4.27	0.000
Reg	Hagoi		Masalog		0.3552	0.1349	196	2.63	0.045
Yr*Reg	Carolina	1982	Diablo	1982	-0.7112	0.1837	572	-3.87	0.007
Yr*Reg	Carolina	1982	Hagoi	1982	-0.3605	0.1976	572	-1.82	0.804
Yr*Reg	Carolina	1982	Masalog	1982	0.4406	0.2188	572	2.01	0.684
Yr*Reg	Carolina	1982	Carolina	1996	-0.3105	0.1942	392	-1.60	0.909
Yr*Reg	Carolina	1982	Diablo	1996	-0.4804	0.1837	572	-2.62	0.275
Yr*Reg	Carolina	1982	Hagoi	1996	-0.3738	0.1976	572	-1.89	0.764
Yr*Reg	Carolina	1982	Masalog	1996	-0.1663	0.2188	572	-0.76	1.000
Yr*Reg	Carolina	1982	Carolina	2008	0.2374	0.1942	392	1.22	0.987
Yr*Reg	Carolina	1982	Diablo	2008	-0.0871	0.1837	572	-0.47	1.000
Yr*Reg	Carolina	1982	Hagoi	2008	0.0120	0.1976	572	0.06	1.000
Yr*Reg	Carolina	1982	Masalog	2008	0.0689	0.2188	572	0.32	1.000
Yr*Reg	Diablo	1982	Hagoi	1982	0.3507	0.1731	572	2.03	0.675
Yr*Reg	Diablo	1982	Masalog	1982	1.1518	0.1969	572	5.85	<.001
Yr*Reg	Diablo	1982	Carolina	1996	0.4007	0.1837	572	2.18	0.564
Yr*Reg	Diablo	1982	Diablo	1996	0.2308	0.1473	392	1.57	0.920
Yr*Reg	Diablo	1982	Hagoi	1996	0.3374	0.1731	572	1.95	0.727
Yr*Reg	Diablo	1982	Masalog	1996	0.5449	0.1969	572	2.77	0.198
Yr*Reg	Diablo	1982	Carolina	2008	0.9486	0.1837	572	5.16	<.001
Yr*Reg	Diablo	1982	Diablo	2008	0.6241	0.1473	392	4.24	0.002
Yr*Reg	Diablo	1982	Hagoi	2008	0.7231	0.1731	572	4.18	0.002
Yr*Reg	Diablo	1982	Masalog	2008	0.7801	0.1969	572	3.96	0.005
Yr*Reg	Hagoi	1982	Masalog	1982	0.8011	0.2100	572	3.82	0.009
Yr*Reg	Hagoi	1982	Carolina	1996	0.0500	0.1976	572	0.25	1.000
Yr*Reg	Hagoi	1982	Diablo	1996	-0.1199	0.1731	572	-0.69	1.000
Yr*Reg	Hagoi	1982	Hagoi	1996	-0.0133	0.1762	392	-0.08	1.000
Yr*Reg	Hagoi	1982	Masalog	1996	0.1942	0.2100	572	0.92	0.999
Yr*Reg	Hagoi	1982	Carolina	2008	0.5979	0.1976	572	3.03	0.105
Yr*Reg	Hagoi	1982	Diablo	2008	0.2734	0.1731	572	1.58	0.916
Yr*Reg	Hagoi	1982	Hagoi	2008	0.3725	0.1762	392	2.11	0.613
Yr*Reg	Hagoi	1982	Masalog	2008	0.4294	0.2100	572	2.05	0.662
Yr*Reg	Masalog	1982	Carolina	1996	-0.7511	0.2188	572	-3.43	0.032
Yr*Reg	Masalog	1982	Diablo	1996	-0.9210	0.1969	572	-4.68	0.000
Yr*Reg	Masalog	1982	Hagoi	1996	-0.8144	0.2100	572	-3.88	0.007
Yr*Reg	Masalog	1982	Masalog	1996	-0.6069	0.2158	392	-2.81	0.179
Yr*Reg	Masalog	1982	Carolina	2008	-0.2033	0.2188	572	-0.93	0.999
Yr*Reg	Masalog	1982	Diablo	2008	-0.5278	0.1969	572	-2.68	0.240
Yr*Reg	Masalog	1982	Hagoi	2008	-0.4287	0.2100	572	-2.04	0.664
Yr*Reg	Masalog	1982	Masalog	2008	-0.3717	0.2158	392	-1.72	0.857
Yr*Reg	Carolina	1996	Diablo	1996	-0.1699	0.1837	572	-0.92	0.999
Yr*Reg	Carolina	1996	Hagoi	1996	-0.0633	0.1976	572	-0.32	1.000

Yr*Reg	Carolina	1996	Masalog	1996	0.1442	0.2188	572	0.66	1.000
Yr*Reg	Carolina	1996	Carolina	2008	0.5479	0.1942	392	2.82	0.175
Yr*Reg	Carolina	1996	Diablo	2008	0.2234	0.1837	572	1.22	0.988
Yr*Reg	Carolina	1996	Hagoi	2008	0.3225	0.1976	572	1.63	0.896
Yr*Reg	Carolina	1996	Masalog	2008	0.3794	0.2188	572	1.73	0.851
Yr*Reg	Diablo	1996	Hagoi	1996	0.1066	0.1731	572	0.62	1.000
Yr*Reg	Diablo	1996	Masalog	1996	0.3141	0.1969	572	1.60	0.910
Yr*Reg	Diablo	1996	Carolina	2008	0.7177	0.1837	572	3.91	0.006
Yr*Reg	Diablo	1996	Diablo	2008	0.3932	0.1473	392	2.67	0.245
Yr*Reg	Diablo	1996	Hagoi	2008	0.4923	0.1731	572	2.84	0.166
Yr*Reg	Diablo	1996	Masalog	2008	0.5493	0.1969	572	2.79	0.188
Yr*Reg	Hagoi	1996	Masalog	1996	0.2075	0.2100	572	0.99	0.998
Yr*Reg	Hagoi	1996	Carolina	2008	0.6112	0.1976	572	3.09	0.088
Yr*Reg	Hagoi	1996	Diablo	2008	0.2867	0.1731	572	1.66	0.887
Yr*Reg	Hagoi	1996	Hagoi	2008	0.3857	0.1762	392	2.19	0.559
Yr*Reg	Hagoi	1996	Masalog	2008	0.4427	0.2100	572	2.11	0.617
Yr*Reg	Masalog	1996	Carolina	2008	0.4037	0.2188	572	1.85	0.792
Yr*Reg	Masalog	1996	Diablo	2008	0.0792	0.1969	572	0.40	1.000
Yr*Reg	Masalog	1996	Hagoi	2008	0.1783	0.2100	572	0.85	1.000
Yr*Reg	Masalog	1996	Masalog	2008	0.2352	0.2158	392	1.09	0.995
Yr*Reg	Carolina	2008	Diablo	2008	-0.3245	0.1837	572	-1.77	0.835
Yr*Reg	Carolina	2008	Hagoi	2008	-0.2254	0.1976	572	-1.14	0.993
Yr*Reg	Carolina	2008	Masalog	2008	-0.1685	0.2188	572	-0.77	1.000
Yr*Reg	Diablo	2008	Hagoi	2008	0.0991	0.1731	572	0.57	1.000
Yr*Reg	Diablo	2008	Masalog	2008	0.1561	0.1969	572	0.79	1.000
Yr*Reg	Hagoi	2008	Masalog	2008	0.0570	0.2100	572	0.27	1.000

Rufous Fantail

Effect	Region	Year	Region	Year	Estimate	SE	DF	*t* Value	Adj *P*
Yr		1982		1996	-0.2980	0.0868	392	-3.43	0.002
Yr		1982		2008	-0.6521	0.0868	392	-7.52	<.001
Yr		1996		2008	-0.3542	0.0868	392	-4.08	0.000
Reg	Carolina		Diablo		0.0887	0.1147	196	0.77	0.866
Reg	Carolina		Hagoi		0.0847	0.1234	196	0.69	0.902
Reg	Carolina		Masalog		0.4970	0.1367	196	3.64	0.002
Reg	Diablo		Hagoi		-0.0040	0.1081	196	-0.04	1.000
Reg	Diablo		Masalog		0.4082	0.1230	196	3.32	0.006
Reg	Hagoi		Masalog		0.4122	0.1312	196	3.14	0.010
Yr*Reg	Carolina	1982	Diablo	1982	-0.4308	0.1748	564	-2.46	0.366
Yr*Reg	Carolina	1982	Hagoi	1982	-0.1465	0.1881	564	-0.78	1.000
Yr*Reg	Carolina	1982	Masalog	1982	0.4411	0.2083	564	2.12	0.610
Yr*Reg	Carolina	1982	Carolina	1996	-0.7967	0.1821	392	-4.38	0.001
Yr*Reg	Carolina	1982	Diablo	1996	-0.2829	0.1748	564	-1.62	0.902
Yr*Reg	Carolina	1982	Hagoi	1996	-0.5348	0.1881	564	-2.84	0.166
Yr*Reg	Carolina	1982	Masalog	1996	0.2863	0.2083	564	1.37	0.968
Yr*Reg	Carolina	1982	Carolina	2008	-0.7584	0.1821	392	-4.17	0.002
Yr*Reg	Carolina	1982	Diablo	2008	-0.5752	0.1748	564	-3.29	0.050

Yr*Reg	Carolina	1982	Hagoi	2008	-0.6196	0.1881	564	-3.29	0.049
Yr*Reg	Carolina	1982	Masalog	2008	-0.7916	0.2083	564	-3.80	0.009
Yr*Reg	Diablo	1982	Hagoi	1982	0.2843	0.1648	564	1.73	0.856
Yr*Reg	Diablo	1982	Masalog	1982	0.8719	0.1874	564	4.65	0.000
Yr*Reg	Diablo	1982	Carolina	1996	-0.3659	0.1748	564	-2.09	0.628
Yr*Reg	Diablo	1982	Diablo	1996	0.1479	0.1381	392	1.07	0.996
Yr*Reg	Diablo	1982	Hagoi	1996	-0.1040	0.1648	564	-0.63	1.000
Yr*Reg	Diablo	1982	Masalog	1996	0.7171	0.1874	564	3.83	0.008
Yr*Reg	Diablo	1982	Carolina	2008	-0.3276	0.1748	564	-1.87	0.775
Yr*Reg	Diablo	1982	Diablo	2008	-0.1444	0.1381	392	-1.05	0.997
Yr*Reg	Diablo	1982	Hagoi	2008	-0.1887	0.1648	564	-1.15	0.992
Yr*Reg	Diablo	1982	Masalog	2008	-0.3608	0.1874	564	-1.92	0.743
Yr*Reg	Hagoi	1982	Masalog	1982	0.5875	0.1999	564	2.94	0.131
Yr*Reg	Hagoi	1982	Carolina	1996	-0.6502	0.1881	564	-3.46	0.030
Yr*Reg	Hagoi	1982	Diablo	1996	-0.1364	0.1648	564	-0.83	1.000
Yr*Reg	Hagoi	1982	Hagoi	1996	-0.3883	0.1652	392	-2.35	0.443
Yr*Reg	Hagoi	1982	Masalog	1996	0.4328	0.1999	564	2.17	0.576
Yr*Reg	Hagoi	1982	Carolina	2008	-0.6120	0.1881	564	-3.25	0.056
Yr*Reg	Hagoi	1982	Diablo	2008	-0.4287	0.1648	564	-2.60	0.282
Yr*Reg	Hagoi	1982	Hagoi	2008	-0.4731	0.1652	392	-2.86	0.159
Yr*Reg	Hagoi	1982	Masalog	2008	-0.6451	0.1999	564	-3.23	0.060
Yr*Reg	Masalog	1982	Carolina	1996	-1.2377	0.2083	564	-5.94	<.001
Yr*Reg	Masalog	1982	Diablo	1996	-0.7240	0.1874	564	-3.86	0.007
Yr*Reg	Masalog	1982	Hagoi	1996	-0.9759	0.1999	564	-4.88	<.001
Yr*Reg	Masalog	1982	Masalog	1996	-0.1548	0.2024	392	-0.76	1.000
Yr*Reg	Masalog	1982	Carolina	2008	-1.1995	0.2083	564	-5.76	<.001
Yr*Reg	Masalog	1982	Diablo	2008	-1.0163	0.1874	564	-5.42	<.001
Yr*Reg	Masalog	1982	Hagoi	2008	-1.0606	0.1999	564	-5.31	<.001
Yr*Reg	Masalog	1982	Masalog	2008	-1.2326	0.2024	392	-6.09	<.001
Yr*Reg	Carolina	1996	Diablo	1996	0.5138	0.1748	564	2.94	0.132
Yr*Reg	Carolina	1996	Hagoi	1996	0.2618	0.1881	564	1.39	0.965
Yr*Reg	Carolina	1996	Masalog	1996	1.0830	0.2083	564	5.20	<.001
Yr*Reg	Carolina	1996	Carolina	2008	0.0382	0.1821	392	0.21	1.000
Yr*Reg	Carolina	1996	Diablo	2008	0.2215	0.1748	564	1.27	0.983
Yr*Reg	Carolina	1996	Hagoi	2008	0.1771	0.1881	564	0.94	0.999
Yr*Reg	Carolina	1996	Masalog	2008	0.0051	0.2083	564	0.02	1.000
Yr*Reg	Diablo	1996	Hagoi	1996	-0.2519	0.1648	564	-1.53	0.932
Yr*Reg	Diablo	1996	Masalog	1996	0.5692	0.1874	564	3.04	0.102
Yr*Reg	Diablo	1996	Carolina	2008	-0.4755	0.1748	564	-2.72	0.221
Yr*Reg	Diablo	1996	Diablo	2008	-0.2923	0.1381	392	-2.12	0.611
Yr*Reg	Diablo	1996	Hagoi	2008	-0.3366	0.1648	564	-2.04	0.663
Yr*Reg	Diablo	1996	Masalog	2008	-0.5087	0.1874	564	-2.71	0.223
Yr*Reg	Hagoi	1996	Masalog	1996	0.8211	0.1999	564	4.11	0.003
Yr*Reg	Hagoi	1996	Carolina	2008	-0.2236	0.1881	564	-1.19	0.990
Yr*Reg	Hagoi	1996	Diablo	2008	-0.0404	0.1648	564	-0.25	1.000
Yr*Reg	Hagoi	1996	Hagoi	2008	-0.0847	0.1652	392	-0.51	1.000
Yr*Reg	Hagoi	1996	Masalog	2008	-0.2568	0.1999	564	-1.28	0.981

Yr*Reg	Masalog	1996	Carolina	2008	-1.0447	0.2083	564	-5.02	<.001
Yr*Reg	Masalog	1996	Diablo	2008	-0.8615	0.1874	564	-4.60	0.000
Yr*Reg	Masalog	1996	Hagoi	2008	-0.9058	0.1999	564	-4.53	0.001
Yr*Reg	Masalog	1996	Masalog	2008	-1.0779	0.2024	392	-5.33	<.001
Yr*Reg	Carolina	2008	Diablo	2008	0.1832	0.1748	564	1.05	0.996
Yr*Reg	Carolina	2008	Hagoi	2008	0.1389	0.1881	564	0.74	1.000
Yr*Reg	Carolina	2008	Masalog	2008	-0.0332	0.2083	564	-0.16	1.000
Yr*Reg	Diablo	2008	Hagoi	2008	-0.0443	0.1648	564	-0.27	1.000
Yr*Reg	Diablo	2008	Masalog	2008	-0.2164	0.1874	564	-1.15	0.992
Yr*Reg	Hagoi	2008	Masalog	2008	-0.1720	0.1999	564	-0.86	0.999

Bridled White-eye

Effect	Region	Year	Region	Year	Estimate	SE	DF	*t* Value	Adj *P*
Yr		1982		1996	0.1766	0.0464	392	3.81	0.001
Yr		1982		2008	0.0071	0.0464	392	0.15	0.987
Yr		1996		2008	-0.1695	0.0464	392	-3.65	0.001
Reg	Carolina		Diablo		0.1128	0.0523	196	2.16	0.139
Reg	Carolina		Hagoi		0.0699	0.0563	196	1.24	0.601
Reg	Carolina		Masalog		0.2577	0.0623	196	4.14	0.000
Reg	Diablo		Hagoi		-0.0429	0.0493	196	-0.87	0.820
Reg	Diablo		Masalog		0.1449	0.0561	196	2.58	0.051
Reg	Hagoi		Masalog		0.1878	0.0598	196	3.14	0.010
Yr*Reg	Carolina	1982	Diablo	1982	-0.0421	0.0878	587	-0.48	1.000
Yr*Reg	Carolina	1982	Hagoi	1982	0.2615	0.0945	587	2.77	0.198
Yr*Reg	Carolina	1982	Masalog	1982	0.2141	0.1046	587	2.05	0.661
Yr*Reg	Carolina	1982	Carolina	1996	0.2121	0.0974	392	2.18	0.566
Yr*Reg	Carolina	1982	Diablo	1996	0.1620	0.0878	587	1.84	0.792
Yr*Reg	Carolina	1982	Hagoi	1996	0.1099	0.0945	587	1.16	0.991
Yr*Reg	Carolina	1982	Masalog	1996	0.6562	0.1046	587	6.27	<.001
Yr*Reg	Carolina	1982	Carolina	2008	-0.0335	0.0974	392	-0.34	1.000
Yr*Reg	Carolina	1982	Diablo	2008	0.3972	0.0878	587	4.52	0.001
Yr*Reg	Carolina	1982	Hagoi	2008	0.0169	0.0945	587	0.18	1.000
Yr*Reg	Carolina	1982	Masalog	2008	0.0813	0.1046	587	0.78	1.000
Yr*Reg	Diablo	1982	Hagoi	1982	0.3037	0.0828	587	3.67	0.015
Yr*Reg	Diablo	1982	Masalog	1982	0.2563	0.0942	587	2.72	0.220
Yr*Reg	Diablo	1982	Carolina	1996	0.2542	0.0878	587	2.89	0.147
Yr*Reg	Diablo	1982	Diablo	1996	0.2041	0.0739	392	2.76	0.200
Yr*Reg	Diablo	1982	Hagoi	1996	0.1520	0.0828	587	1.84	0.797
Yr*Reg	Diablo	1982	Masalog	1996	0.6983	0.0942	587	7.42	<.001
Yr*Reg	Diablo	1982	Carolina	2008	0.0086	0.0878	587	0.10	1.000
Yr*Reg	Diablo	1982	Diablo	2008	0.4393	0.0739	392	5.95	<.001
Yr*Reg	Diablo	1982	Hagoi	2008	0.0590	0.0828	587	0.71	1.000
Yr*Reg	Diablo	1982	Masalog	2008	0.1235	0.0942	587	1.31	0.977
Yr*Reg	Hagoi	1982	Masalog	1982	-0.0474	0.1004	587	-0.47	1.000
Yr*Reg	Hagoi	1982	Carolina	1996	-0.0495	0.0945	587	-0.52	1.000
Yr*Reg	Hagoi	1982	Diablo	1996	-0.0996	0.0828	587	-1.20	0.989
Yr*Reg	Hagoi	1982	Hagoi	1996	-0.1517	0.0884	392	-1.72	0.860

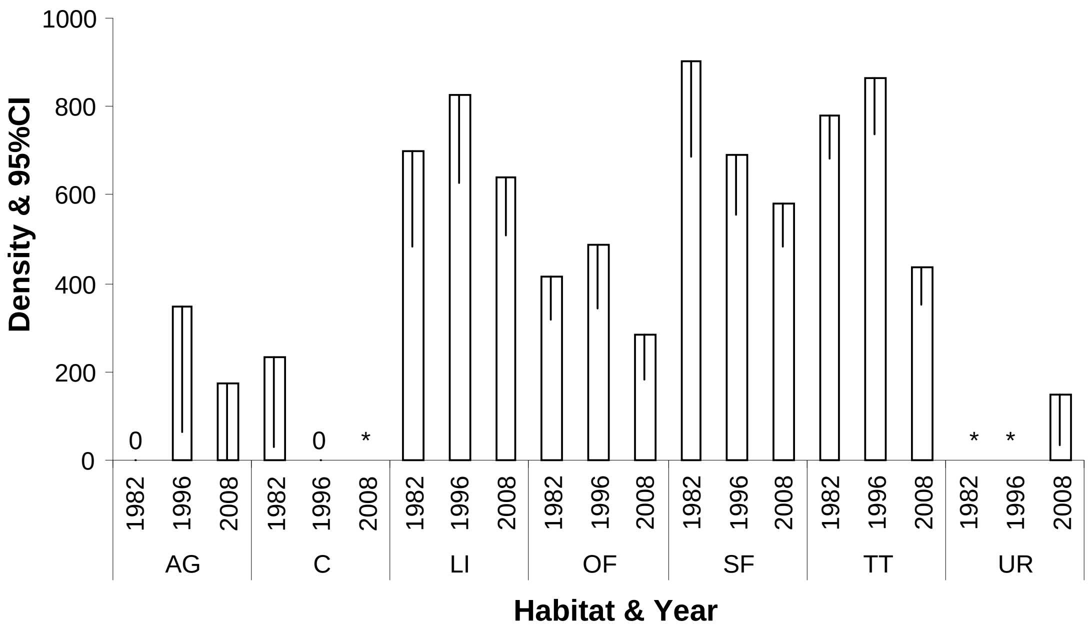
Yr*Reg	Hagoi	1982	Masalog	1996	0.3946	0.1004	587	3.93	0.006
Yr*Reg	Hagoi	1982	Carolina	2008	-0.2950	0.0945	587	-3.12	0.081
Yr*Reg	Hagoi	1982	Diablo	2008	0.1357	0.0828	587	1.64	0.894
Yr*Reg	Hagoi	1982	Hagoi	2008	-0.2447	0.0884	392	-2.77	0.198
Yr*Reg	Hagoi	1982	Masalog	2008	-0.1802	0.1004	587	-1.79	0.820
Yr*Reg	Masalog	1982	Carolina	1996	-0.0021	0.1046	587	-0.02	1.000
Yr*Reg	Masalog	1982	Diablo	1996	-0.0522	0.0942	587	-0.55	1.000
Yr*Reg	Masalog	1982	Hagoi	1996	-0.1043	0.1004	587	-1.04	0.997
Yr*Reg	Masalog	1982	Masalog	1996	0.4420	0.1082	392	4.09	0.003
Yr*Reg	Masalog	1982	Carolina	2008	-0.2476	0.1046	587	-2.37	0.431
Yr*Reg	Masalog	1982	Diablo	2008	0.1831	0.0942	587	1.94	0.730
Yr*Reg	Masalog	1982	Hagoi	2008	-0.1972	0.1004	587	-1.96	0.717
Yr*Reg	Masalog	1982	Masalog	2008	-0.1328	0.1082	392	-1.23	0.987
Yr*Reg	Carolina	1996	Diablo	1996	-0.0501	0.0878	587	-0.57	1.000
Yr*Reg	Carolina	1996	Hagoi	1996	-0.1022	0.0945	587	-1.08	0.995
Yr*Reg	Carolina	1996	Masalog	1996	0.4441	0.1046	587	4.25	0.002
Yr*Reg	Carolina	1996	Carolina	2008	-0.2455	0.0974	392	-2.52	0.329
Yr*Reg	Carolina	1996	Diablo	2008	0.1851	0.0878	587	2.11	0.617
Yr*Reg	Carolina	1996	Hagoi	2008	-0.1952	0.0945	587	-2.07	0.648
Yr*Reg	Carolina	1996	Masalog	2008	-0.1307	0.1046	587	-1.25	0.985
Yr*Reg	Diablo	1996	Hagoi	1996	-0.0521	0.0828	587	-0.63	1.000
Yr*Reg	Diablo	1996	Masalog	1996	0.4942	0.0942	587	5.25	<.001
Yr*Reg	Diablo	1996	Carolina	2008	-0.1954	0.0878	587	-2.23	0.532
Yr*Reg	Diablo	1996	Diablo	2008	0.2352	0.0739	392	3.19	0.068
Yr*Reg	Diablo	1996	Hagoi	2008	-0.1451	0.0828	587	-1.75	0.842
Yr*Reg	Diablo	1996	Masalog	2008	-0.0806	0.0942	587	-0.86	0.999
Yr*Reg	Hagoi	1996	Masalog	1996	0.5463	0.1004	587	5.44	<.001
Yr*Reg	Hagoi	1996	Carolina	2008	-0.1433	0.0945	587	-1.52	0.935
Yr*Reg	Hagoi	1996	Diablo	2008	0.2874	0.0828	587	3.47	0.028
Yr*Reg	Hagoi	1996	Hagoi	2008	-0.0930	0.0884	392	-1.05	0.996
Yr*Reg	Hagoi	1996	Masalog	2008	-0.0285	0.1004	587	-0.28	1.000
Yr*Reg	Masalog	1996	Carolina	2008	-0.6897	0.1046	587	-6.59	<.001
Yr*Reg	Masalog	1996	Diablo	2008	-0.2590	0.0942	587	-2.75	0.206
Yr*Reg	Masalog	1996	Hagoi	2008	-0.6393	0.1004	587	-6.37	<.001
Yr*Reg	Masalog	1996	Masalog	2008	-0.5748	0.1082	392	-5.31	<.001
Yr*Reg	Carolina	2008	Diablo	2008	0.4307	0.0878	587	4.90	<.001
Yr*Reg	Carolina	2008	Hagoi	2008	0.0504	0.0945	587	0.53	1.000
Yr*Reg	Carolina	2008	Masalog	2008	0.1148	0.1046	587	1.10	0.995
Yr*Reg	Diablo	2008	Hagoi	2008	-0.3803	0.0828	587	-4.60	0.000
Yr*Reg	Diablo	2008	Masalog	2008	-0.3159	0.0942	587	-3.35	0.041
Yr*Reg	Hagoi	2008	Masalog	2008	0.0645	0.1004	587	0.64	1.000

Micronesian Starling

Effect	Region	Year	Region	Year	Estimate	SE	DF	*t* Value	Adj *P*
Yr		1982		1996	0.0097	0.0677	392	0.14	0.989
Yr		1982		2008	-0.6479	0.0677	392	-9.57	<.001
Yr		1996		2008	-0.6576	0.0677	392	-9.72	<.001

Reg	Carolina	Diablo	-0.0766	0.0877	196	-0.87	0.819
Reg	Carolina	Hagoi	0.0316	0.0944	196	0.34	0.987
Reg	Carolina	Masalog	0.2310	0.1045	196	2.21	0.124
Reg	Diablo	Hagoi	0.1082	0.0827	196	1.31	0.558
Reg	Diablo	Masalog	0.3076	0.0941	196	3.27	0.007
Reg	Hagoi	Masalog	0.1994	0.1003	196	1.99	0.196

Appendix 3. Break down of the Tinian Monarch population by habitat and year



Appendix 3, Figure 10. Plot of Tinian Monarch density estimates (birds/km^2) and lower 95% confidence interval by habitat and year from all transects (10 in 1982 and 1996, and 14 in 2008). Habitat types are AG–agriculture, C–coastal, LI–limestone forest, OF–open field, SF–secondary forest, TT–tangantangan thicket, and UR–urban/residential. No birds were detected in the agriculture habitat in 1982 or coastal habitat in 1996. No stations (indicated with *) were surveyed in the coastal habitat in 2008, and urban/residential habitat in 1996 and 2008.

Appendix 3, Table 14. Tinian Monarch density estimates (birds/km^2), standard error (SE), and 95% confidence intervals (Lower and Upper 95% CI) by habitat and year from all transects (10 in 1982 and 1996, and 14 in 2008). Habitat types are AG–agriculture, C–coastal, LI–limestone forest, OF–open field, SF–secondary forest, TT–tangantangan thicket, and UR–urban/residential. No birds were detected in the agriculture habitat in 1982 or coastal habitat in 1996. No stations (indicated with *) were surveyed in the coastal habitat in 2008, and urban/residential habitat in 1996 and 2008.

Habitat	Year	Estimate	SE	L 95% CI	U 95% CI
AG	1982	0.0			
	1996	349.4	201.96	63.561	1920.800
	2008	174.7	174.77	†	†
C	1982	232.9	116.66	30.770	1763.400
	1996	0.0			
	2008	*			
LI	1982	698.8	123.97	483.410	1010.200
	1996	825.9	111.49	625.330	1090.700
	2008	640.6	73.54	509.490	805.400
OF	1982	414.9	56.68	316.340	544.230
	1996	485.8	84.62	342.690	688.560
	2008	283.3	63.74	180.590	444.440
SF	1982	901.1	117.05	687.880	1180.400
	1996	691.2	76.45	553.930	862.540
	2008	582.4	54.28	483.960	700.740
TT	1982	778.2	51.52	682.940	886.810
	1996	863.2	68.80	737.510	1010.400
	2008	435.7	46.84	352.230	539.030
UR	1982	*			
	1996	*			
	2008	149.8	103.99	32.300	694.240

† Sample size was insufficient to estimate reliable confidence intervals.

Appendix 3, Table 15. Comparison of Tinian Monarch densities by habitat and year using repeated measures ANOVA from all transects (10 in 1982 and 1996, and 14 in 2008). Year and habitat fixed effects were significant but the year and habitat interaction was non-significant ($F_{8, 623} = 0.62$, $p = 0.764$); therefore, only effects by habitat are presented here. Differences among years are presented in Table 4. Significant differences are highlighted in bold. Habitat types are LI–limestone forest, OF–open field, SF–secondary forest, and TT–tangantangan thicket; agriculture, coastal, and urban/residential (ACU) habitats were combined because insufficient numbers of stations were sampled in those habitats.

Effect	Num DF	Den DF	*F* Value	Pr > *F*
Habitat	4	645	15.04	<.0001

Effect	Effect	Estimate	Error	*t* Value	Adj *P*
ACU	**LI**	**-1.002**	**0.250**	**-4.00**	**<.001**
ACU	OF	-0.354	0.243	-1.45	0.592
ACU	**SF**	**-0.958**	**0.245**	**-3.91**	**<.001**
ACU	**TT**	**-0.999**	**0.236**	**-4.23**	**<.001**
LI	**OF**	**0.648**	**0.132**	**4.91**	**<.001**
LI	SF	0.044	0.134	0.33	0.998
LI	TT	0.003	0.118	0.03	1.000
OF	**SF**	**-0.604**	**0.119**	**-5.10**	**<.001**
OF	**TT**	**-0.645**	**0.100**	**-6.43**	**<.001**
SF	TT	-0.041	0.102	-0.40	0.995

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Main Papers

Conservation and Protected Areas on South-Pacific Islands: The Importance of Tradition

Jeremy Carew-Reid [p1]

The natural environments of the South Pacific Islands are degrading rapidly. The region suffers one of the highest rates of species extinction in the world, and has probably the world's highest proportion of endangered species per unit land-area. Most island ecosystems in the South Pacific are totally unprotected, and many are rapidly diminishing in area or at least deteriorating in quality. The practice of conservation through conventional forms of protected areas has been ineffective in Pacific countries, having been applied in ignorance or denial of traditional practices or tenurial arrangements when such traditional patterns are often crucial to the maintenance of South Pacific cultures. Only approaches to conservation which embrace the multiple and subsistence uses of natural resources by island communities are having success.

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EPA SITE CHARACTERIZATION FOR MUNITIONS CONSTITUENTS

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EPA Federal Facilities Forum Issue Paper:
SITE CHARACTERIZATION FOR MUNITIONS CONSTITUENTS

This paper was prepared by: T.F. Jenkins[2], S.R. Bigl[1], A.D. Hewitt[1*], J.L. Clausen[1], H.D. Craig[5], M.E. Walsh[1], R. Martel[3], K. Nieman[4], S. Taylor[1], and M.R. Walsh[1]. Technical guidance and direction in the development of this paper was provided by members of the Federal Facilities Forum Munitions Subcommittee: S. Tzhone[6], R. Mayer[6], S. Hirsh[7], H.D. Craig[5], M. McEaddy[8], D. Maddox[8], M.T. Cooke[8]. For further information on this document, contact Monica McEaddy at (703) 603-0044. The Federal Facilities Forum website is online at: http://www.epa.gov/tio/tsp/fedforum.htm

This Federal Facilities Forum Issue Paper: Site Characterization For Munitions Constituents was prepared to provide remedial project managers and other federal, state, and private personnel working on hazardous waste sites the technical information needed to make decisions regarding the nature of energetic residues on Department of Defense training ranges (and other munitions sites such as Formerly Used Defense Sites), sampling strategies that provide representative samples, and analytical methods developed to characterize these samples.

This paper is not intended to include discussions of the safety issues associated with sites contaminated with energetic residues. Examples of explosives safety issues include, but are not limited to: geophysical detection methods, explosion (detonation) hazards, toxicity of secondary explosives, and personal protective equipment. Information pertaining to geophysical investigations has been summarized by ESTCP/ITRC (2006) and toxicity concerns can be found in Roberts and Hartley (1992), Yinon (1990), and Sunahara et al. (2009). Also, this paper is not intended to serve as a guide for geophysical investigation of unexploded ordnance (UXO) or discarded military munitions (DMM), or chemical sampling and analysis of bulk high explosives, primary explosives where concentrations exceed 20,000 mg/kg (2%), or secondary explosives in soil where concentrations exceed 100,000 mg/kg (10%).

It is imperative that any persons working on sites thought to be contaminated with energetic residues thoroughly familiarize themselves with the physical and toxic properties of the materials potentially present and take all measures as may be prudent and/or prescribed by law to protect life, health, and property. These conditions present a potential detonation hazard; therefore, explosive safety procedures and safety precautions should be identified before initiating site characterization activities in such environments.

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Glossary of Terms[1]

Blow-in-place. Method used to destroy UXO/DMM, by use of additional explosives, in the location the item is encountered.

Caliber. The diameter of a projectile or the diameter of the bore of a gun or launching tube. Caliber is usually expressed in millimeters or inches. In some instances (primarily with naval ordnance), caliber is also used as a measure of the length of a weapon's barrel. For example, the term "5 inch 38 caliber" describes ordnance used in a 5-inch gun with a barrel length that is 38 times the diameter of the bore. [4]

Casing. The fabricated outer part of ordnance designed to hold an explosive charge and the mechanism required to detonate this charge.

Deflagration. A rapid chemical reaction occurring at a rate of less than 3,300 feet per second in which the output of heat is enough to enable the reaction to proceed and be accelerated without input of heat from another source. The effect of a true deflagration under confinement is an explosion. Confinement of the reaction increases pressure, rate of reaction, and temperature, and may cause transition into a detonation. [5]

Detonation. A violent chemical reaction within a chemical compound or mechanical mixture evolving heat and pressure. The result of the chemical reaction is exertion of extremely high pressure on the surrounding medium. The rate of a detonation is supersonic, above 3,300 feet per second. [2]

Discarded Military Munitions (DMM). Military munitions that have been abandoned without proper disposal or removed from storage in a military magazine or other storage area for the purpose of disposal. The term does not include unexploded ordnance, military munitions that are being held for future use or planned disposal, or military munitions that have been properly disposed of consistent with applicable environmental laws and regulations 10 U.S.C. 2710 (e)(2). [10]

Dud-fired. Munitions that failed to function as intended or as designed. They can be armed or not armed as intended or at some stage in between.

Explosion. A chemical reaction of any chemical compound or mechanical mixture that, when initiated, undergoes a very rapid combustion or decomposition, releasing large volumes of highly heated gases that exert pressure on the surrounding medium. Also, a mechanical reaction in which failure of the container causes sudden release of pressure from within a pressure vessel. Depending on the rate of energy release, an explosion can be categorized as a deflagration, a detonation, or pressure rupture. [2]

[1] Terms as defined in US EPA. 2005. EPA Handbook on the Management of Munitions Response Actions; Interim Final.

Explosive. A substance or mixture of substances, which is capable, by chemical reaction, of producing gas at such a temperature, pressure and rate as to be capable of causing damage to the surroundings.

Explosive filler. The energetic compound or mixture inside a munitions item.

Explosive ordnance disposal (EOD). The detection, identification, field evaluation, rendering-safe recovery, and final disposal of unexploded ordnance or munitions. It may also include the rendering-safe and/or disposal of explosive ordnance that has become hazardous by damage or deterioration, when the disposal of such explosive ordnance is beyond the capabilities of the personnel normally assigned the responsibilities for routine disposal. EOD activities are performed by active duty military personnel. [7]

Explosive soil. Explosive soil refers to any mixture of explosives in soil, sand, clay, or other solid media at concentrations such that the mixture itself is reactive or ignitable. The concentration of a particular explosive in soil necessary to present an explosion hazard depends on whether the explosive is classified as "primary" or "secondary." Guidance on whether an explosive is classified as "primary" or "secondary" can be obtained from Chapters 7 and 8 of TM 9-1300-214, Military Explosives. [1]

Explosive train. The arrangement of different explosives in munitions arranged according to the most sensitive and least powerful to the least sensitive and most powerful (initiator - booster - burster). A small quantify of an initiating compound or mixture, such as lead azide, is used to detonate a larger quantity of a booster compound, such as tetryl, that results in the main or booster charge of a RDX composition, TNT, or other compound or mixture detonating.

Formerly Used Defense Site (FUDS). Real property that was formerly owned by, leased by, possessed by, or otherwise under the jurisdiction of the Secretary of Defense or the components, including organizations that predate DoD. [1]

Fragmentation. The breaking up of the confining material of a chemical compound or mechanical mixture when an explosion occurs. Fragments may be complete items, subassemblies, or pieces thereof, or pieces of equipment or buildings containing the items. [2]

Fuze. 1. A device with explosive components designed to initiate a train of fire or detonation in ordnance. 2. A non-explosive device designed to initiate an explosion in ordnance. [3]

Ground-penetrating radar. A system that uses pulsed radio waves to penetrate the ground and measure the distance and direction of subsurface targets through radio waves that are reflected back to the system.

Magnetometer. An instrument for measuring the intensity of magnetic fields.

Military munitions. All ammunition products and components produced for or used by the armed forces for national defense and security, including ammunition products or components under the control of the Department of Defense, the Coast Guard, the Department of Energy, and the National Guard. The term includes confined gaseous, liquid, and solid propellants, explosives, pyrotechnics, chemical and riot control agents, chemical munitions, rockets, guided and ballistic missiles, bombs, warheads, mortar rounds, artillery ammunition, small arms ammunition, grenades, mines, torpedoes, depth charges, cluster munitions and dispensers, demolition charges, and devices and components thereof.

The term does not include wholly inert items, improvised explosive devices, and nuclear weapons, nuclear devices, and nuclear components, other than non-nuclear components of nuclear devices that are managed under the nuclear weapons program of the Department of Energy after all required sanitization operations under the Atomic Energy Act of 1954 (42 U.S.C. 2011 et seq.) have been completed (10 U.S.C. 101 (e)(4). [10]

Munitions constituents (MC). Any materials originating from unexploded ordnance, discarded military munitions, or other military munitions, including explosive and nonexplosive materials, and emission, degradation, or breakdown elements of such ordnance or munitions. (10 U.S.C. 2710 (e)(4)).[10] Munitions constituents may be subject to other statutory authorities, including but not limited to CERCLA (42 U.S.C. 9601 et seq.) and RCRA (42 U.S.C. 6901 et seq.).

Munitions and Explosives of Concern (MEC). This term, which distinguishes specific categories of military munitions that may pose unique explosives safety risks, means: (1) Unexploded ordnance (UXO); (2) Discarded military munitions (DMM); or (3) Munitions Constituents (e.g. TNT, RDX) present in high enough concentrations to pose an explosive hazard. Formerly known as Ordnance and Explosives (OE). [10]

Open burning. The combustion of any material without (1) control of combustion air, (2) containment of the combustion reaction in an enclosed device, (3) mixing for complete combustion, and (4) control of emission of the gaseous combustion products. [6]

Open detonation. A chemical process used for the treatment of unserviceable, obsolete, and/or waste munitions whereby an explosive donor charge initiates the munitions to be detonated. [6]

Operational range. A range that is under the jurisdiction, custody, or control of the Secretary of Defense and (A) that is used for range activities; or (B) although not currently being used for range activities, that is still considered by the Secretary to be a range and has not been put to a new use that is incompatible with range activities. [10]

Practice ordnance. Ordnance manufactured to serve a training purpose. Practice ordnance generally does not carry a full explosive payload. Practice ordnance may still contain explosive components such as spotting charges, bursters, and propulsion charges. [9]

Projectile. An object projected by an applied force and continuing in motion by its own inertia, as mortar, small arms, and artillery projectiles. Also applied to rockets and to guided missiles.

Propellant. An agent such as an explosive powder or fuel that can be made to provide the necessary energy for propelling ordnance.

Range. Means designated land and water areas set aside, managed, and used to research, develop, test and evaluate military munitions and explosives, other ordnance, or weapon systems, or to train military personnel in their use and handling. Ranges include firing lines and positions, maneuver areas, firing lanes, test pads, detonation pads, impact areas, and buffer zones with restricted access and exclusionary areas. (40 CFR § 266.601) A recent statutory change added Airspace areas designated for military use in accordance with regulations and procedures prescribed by the Administrator of the Federal Aviation Administration. (10 U.S.C. 101 (e)(3)).

Unexploded ordnance (UXO). These Guidelines will use the term "UXO" as defined in the Military Munitions Rule. "UXO means military munitions that have been primed, fuzed, armed, or otherwise prepared for action, and have been fired, dropped, launched, projected, or placed in such a manner as to constitute a hazard to operations, installation, personnel, or material and that remain unexploded either by malfunction, design, or any other cause." This definition also covers all ordnance-related items (e.g., low-order fragments) existing on a non-operational range. (40 CFR Part 266.201, 62 FR 6654, February 12, 1997).[8]

Warhead. The payload section of a guided missile, rocket, or torpedo.

Sources:

1. U.S. Army Corps of Engineers Pamphlet No. 1110-1-18, "Engineering and Design Ordnance and Explosives Response," April 24, 2000.
2. DoD 6055.9-STD, Department of Defense Ammunition and Explosives Safety Standards.
3. Federal Advisory Committee for the Development of Innovative Technologies, "Unexploded Ordnance (UXO): An Overview," Naval Explosive Ordnance Disposal Technology Division, UXO Countermeasures Department, October 1996.
4. National Oil and Hazardous Substances Pollution Contingency Plan (more commonly called the National Contingency Plan), 40 C.F.R. § 300 et seq.
5. Department of Defense Directive 6055.9. "DoD Explosives Safety Board (DDESB) and DoD Component Explosives Safety Responsibilities," July 29, 1996.
6. Department of Defense. Policy to Implement the EPA's Military Munitions Rule. July 1, 1998.
7. Joint Publication 1-02, "DoD Dictionary of Military and Associated Terms," April 12, 2001.
8. Military Munitions Rule: Hazardous Waste Identification and Management; Explosives Emergencies; Manifest Exception for Transport of Hazardous Waste on Right-of-Ways on Contiguous Properties, Final Rule, 40 C.F.R. § 260 et seq.
9. Former Fort Ord, California, Draft Ordnance Detection and Discrimination Study Work Plan, Sacramento District, U.S. Army Corps of Engineers. Prepared by Parsons. August 18, 1999.
10. Department of Defense Memorandum, "Definitions Related to Munitions Response Actions," from the Office of the Under Secretary of Defense, December 18, 2003.

Nomenclature

Term	Description
1,3,-5-TNB	1,3,5-Trinitrobenzene
3,5-DNA	3,5-Dinitroanaline
2,4-DNT	2,4-Dinitrotoluene
2,6-DNT	2,6-Dinitrotoluene
2AmDNT	2-amino-4,6-dinitrotoluene
4AmDNT	4-amino-2,6-dinitrotoluene
AEC	Army Environmental Command
AEHA	Army Environmental Hygiene Agency
Akardite	1-methyl-3,3-diphenylurea
C4	Composition C4 (91% RDX, 9% oil)
CFB	Canadian Forces Base
CHPPM	Center for Health Promotion and Preventive Medicine
CL-20	2,4,6,8,10,12-hexanitro-2,4,6,8,10,12-hexaazaisowurtzitane
CMDB	Composite Modified Double Base
Comp B	Composition B (60% RDX, 39% TNT, 1% wax)
CRREL	US Army Cold Regions Research and Engineering Laboratory
DDNP	Diazodinitrophenol
DEGDN	Diethylene glycol dinitrate
Decision Unit	The area that a soil sample is intended to represent, called the sampling unit in this document
DMM	Discarded Military Munitions
DNA	Dinitroanaline
DNT	Dinitrotoluene
DoD	U.S. Department of Defense
DPA	Diphenylamine
DQO	Data Quality Objectives
EDGN	Ethylene Glycol Dinitrate
EIS	Environmental Impact Statement
EOD	Explosive Ordnance Disposal
EPA	Environmental Protection Agency
ERDC	Engineering Research and Development Center
ERF	Eagle River Flats
Ethyl Centralite	Diethyl-1,3-diphenylurea
Explosive D	Ammonium Picrate
FUD	Formerly Used Defense site

Term	Description
GC	Gas Chromatography
H-6	RDX, TNT, aluminum
HE	High Explosive
HEP	High-explosive Plastic
HMX	Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetreazocine (High-Melting Explosive)
HPLC	High Performance Liquid Chromatography
HTPB	Hydroxy-terminated polybutadiene
KDNBF	Potassium Dinitrobenzofuroxane
LAW	Light Anti-armor Weapon
LC/ESI/MS	Liquid Chromatography/Electrospray Ionization/Mass Spectrometry
LIDAR	Light detection and ranging
LMNR	Lead Mononitroresorcinate
MC	Munition constituents
MEC	Munitions and Explosives of Concern
MIS	*MULTI-INCREMENT*® sample, sometimes called Incremental Sample (IS)
MLRS	Multiple Launch Rocket System
MMR	Massachusetts Military Reservation, also referred to as Camp Edwards
MMRP	Military Munitions Response Program
MS	Mass Spectrometry
NEW	Net explosive weight
NC	Nitrocellulose
NDPA	N-Nitrosodiphenylamine
NG	Nitroglycerin
NQ	Nitroguanidine
OB	Open Burn
Octol	70 % HMX, 30% TNT
OD	Open Detonation
OSW	Office of Solid Waste
PCN	Polychlorinated naphthalene
PETN	Pentaerythritol Tetranitrate
QA/QC	Quality Assurance/Quality Control

Term	Description
RCRA	Resource Conservation and Recovery Act
RDX	Hexahydro-1,3,5-trinitro-1,3,5-triazine (Royal Demolition Explosive), cyclonite
RSD	Relative Standard Deviation
RPD	Relative Percent Difference
Sampling Unit	The area that a soil sample is intended to represent
SERDP	Strategic Environmental Research and Development Program
SI	Site Investigation
TATB	1,3,5-Triamino-2,4,6-trinitrobenzene
Tetryl	Methyl-2,4,6-trinitrophenyl nitramine
TNT	2,4,6-Trinitrotoluene
TNB	1,3,5-Trinitrobenzene
TOW	Tube-launched, Optically tracked, Wire-guided missile
Tritonal	70:30 or 80:20 mix of TNT and aluminum powder
TTU	Thermal Treatment Unit
UCL	Upper Confidence Limit
USACE	U.S. Army Corps of Engineers
US EPA	U.S. Environmental Protection Agency
UTTR	Utah Test and Training Range
UV	Ultraviolet detector
UXO	Unexploded Ordnance
WP	White Phosphorus

Introduction

Purpose and Scope

The main focus of this issue paper is to provide remedial project managers and corrective action project officers with a summary of information regarding the nature of munition constituents (MC) with an emphasis on energetic residues and metals at military training ranges and munitions open burn (OB) and open detonation (OD) demolition units. For this document, MC will refer to chemicals associated with military explosives and propellants. This will include some background on the physical and chemical properties of energetic chemicals and residues, how residues are deposited and amounts of residue produced from different detonations and firing activities, results of investigations describing the accumulation and distribution of residues at different types of military ranges and OB/OD units, a comparison of methods for the collection of representative soil samples on ranges, and a summary of laboratory methods designed to provide adequate characterization of these soil samples. White phosphorus is discussed in a case study in Appendix A1, but no other smoke munitions or illumination munitions will be discussed in this document.

Background

For the purpose of this document, energetic compounds are those chemicals used by the U.S. Department of Defense (DoD) as propellants and explosives in military munitions and blasting agents. In general, energetic compounds are substances able to undergo exothermic reactions at extremely fast rates producing gaseous products at high pressure and temperature. Substances undergoing this type of behavior can initiate a propagation wave. If the velocity of this wave is less than the speed of sound for a given substance, the substance is said to undergo deflagration (rapid burning). If the velocity is supersonic, the substance is said to undergo a detonation (US Army 1993). Some energetic compounds that undergo deflagration are used by the DoD as propellants to send munitions projectiles or warheads down range. Compounds that can undergo detonations are used in the projectiles or warheads as explosives as shown in Figure 1. Although significant engineering differences exist between explosive trains and ignition trains, in concept they are very similar. In both, a small electrical or mechanical stimulating impetus is magnified via a succession of intermediate charges to achieve optimum initiation of the main charge or propellant load. The major difference between the two types of chains is in the component charges' rates of reaction.

Because both propellants and explosives react at very high temperatures (for TNT about 3000 degrees K), the reactions tend to go to completion forming mainly gaseous products. For TNT (2,4,6-trinitrotoluene, or $C_7H_5N_3O_6$), the reaction is as shown in equation 1 below:

$$(1)\quad 4\ C_7H_5N_3O_6 \longrightarrow 7\ CO_2 + 21\ C + 6\ N_2 + 10\ H_2O.$$

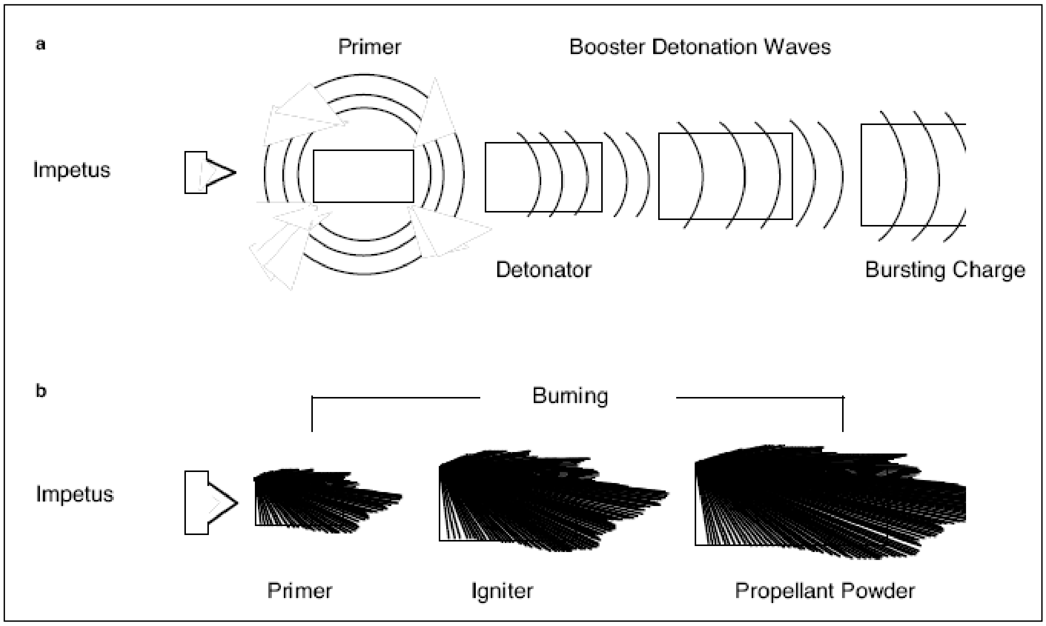


Figure 1. Comparison of explosive train (a) with ignition train (b).
Source: Boudeau (1993) as adapted from US Army (1993).

Because TNT has insufficient oxygen in the molecule relative to carbon, the detonation produces soot (solid C). For many years, it was thought that residues of energetic compounds from high order detonations (detonations that function as designed) would be minimal because of the high temperature and pressures that occur during these processes.

Energetic chemicals

Most energetic chemicals used by the DoD fall into one of three groups – nitroaromatics, nitramines or nitrate esters (Fig. 2). Among the nitroaromatics, TNT (2,4,6-trinitrotoluene) is widely used as an explosive, and DNT (2,4-dinitrotoluene) as a component of many single-base propellants. RDX (hexahydro-1,3,5-trinitro-1,3,5-triazine) and HMX (octahydro-1,3,5,7-tetranitro-1,3,5,7-tetreazocine) are nitramines used in various explosives, and NG (nitroglycerin) and NC (nitrocellulose) are nitrate esters used in gun and some rocket propellants. Table 1 summarizes the energetic chemicals present in current military explosives. Some older energetic formulations contain compounds such as tetryl (methyl-2,4,6-trinitrophenyl nitramine) or ammonium picrate, but these compounds are rarely encountered at training ranges. Table 2 provides some compositions of other explosive formulations used in the past; this information may be useful for older active ranges or formerly used ranges. The discussions will concentration on the major energetic components present in current munitions. Other chemicals may be present in specific munitions but they have not been studied extensively and will not be discussed here.

Information on the content of a specific munition may be found in Army manuals (e.g. US Army 1990, 1993) and from online sources such as:

- The Munitions Items Disposition Action System (MIDAS).
- MVS Munitions Datbase. [CD sent on request by U.S. Army Corps of Engineers Military Munitions Center of Expertise (EMCX)]
- ORDATA. http://ordatamines.maic.jmu.edu/default.aspx

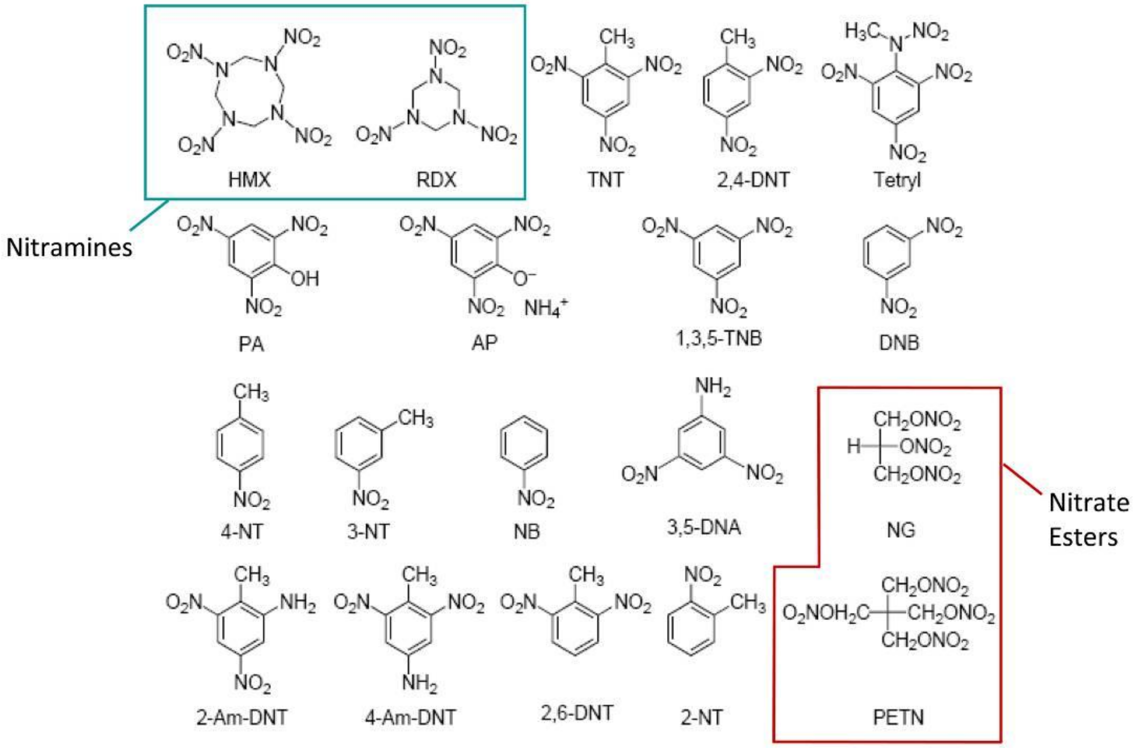


Figure 2. Structures of the nitramines (upper left), nitrate esters (lower right), and nitroaromatic explosives (all others) analyzed in the environment (from Tomkins 2000).

Table 1. Energetic chemicals present in current military explosive and propellant formulations.

Compound	Uses	Chemical Ingredients
Explosive formulations		
Composition B	Artillery; mortar	60% Military-grade RDX (Contains ≈ 10% HMX) 39% Military-grade TNT (Contains ≈ 1% other TNT isomers and DNTs); 1 % wax
Composition C4	Demolition explosive	91% Military-grade RDX
Tritonal	Air Force bombs	Military-grade TNT, aluminum
Composition A4	40-mm grenades	Military-grade RDX
TNT	Artillery	Military-grade TNT
Composition H-6	Navy and Marine bombs	Military-grade RDX and TNT, aluminum
Octol	Antitank rockets	Military-grade HMX and TNT
Explosive D	Naval projectiles	Ammonium Picrate

Table 2. Summary of explosive chemicals present in various military munitions (from Walsh et al. 1993; sources: U.S. Army 1990, U.S. Army Materiel Command 1971).

Composition	Use	Explosives Present (%)				
		TNT	RDX	HMX	DNT	Others
Anatols	a,b	20–50				Ammonium nitrate
Comp A	c,d,e,f		91–98			
Comp B	b,e,f,j	40	55–60			
Comp C	k		88			
Comp C2	k	5	79		12	m-nitrotoluene, nitrocellulose
Comp C3	h,k	4	77		10	m-nitrotoluene, nitrocellulose, tetryl
Comp C4	g		91			
Cyclotol	b,e,f,i	25	75			
HBX–3	m	29	31			
H–6	a,m	30	45			Aluminum
HTA–3	a,b	29		49		
Minol–2	a,l	40				Ammonium nitrate
Torpex	a,f,l	40	42			
DBX	l	40	21			Ammonium nitrate
PBX			0–95	0–95		Trinitrobenzene
Baratol	a	33				Barium nitrate
Baranal	a	35				Barium nitrate
Black powder	n,o					Potassium nitrate
Explosive D	a,b					Ammonium picrate
PTX–1	g,p	20	30			Tetryl
PTX–2	f,i		28–33	41–44		PETN
Comp CH6	d		98			
Ednatols	a,c,i	40–50				Ethylene dinitramine
LX–14				96		
Octols	a,b,f,i	25–35			70–75	
Pentolite	f,g,i	25–90				PETN
Picratol	h					Ammonium picrate
Tetrytols	i,k	65–80				Tetryl
Tritonal	a	80				Aluminum
Amatex 20	c	40	40			Ammonium nitrate
HBX–1	m	40	38			

a Bombs
b High energy projectiles
c Projectile filler
d Boosters
e Grenades
f Shaped charges
g Demolition explosives
h Ammunition
i Bursting charges
j Fragmentation charge
k Former used demolition explosive
l Depth charges
m High energy charge
n Igniter powder
o Time fuses
p Land mines

Gun and Small Rocket Propellant Formulations

Composition

Solid propellants for small arms, artillery, and mortars are low-explosive materials designed to burn at a controlled rate and rapidly produce gases, creating the pressure to accelerate projectiles from guns or propel rockets toward targets (US Army 1993, Folly and Mäder 2004). The rapid but controlled burning of low explosives such as propellants is known as deflagration.

Propellant formulations contain several components, with the primary being an energetic material, commonly a nitro-containing organic chemical such as NC, often combined with other energetic compounds such as DNT, NG, NQ (nitroguanidine), and HMX. Also included are compounds that modify burn rate, binders or plasticizers (both energetic and inert) that enable loading and packing the propellant into the projectile, and lastly, stabilizer compounds that absorb nitrogen oxides, the breakdown products of NC, to increase propellant stability during storage. Solid propellants used for rocket fuel [termed "composite" or "composite modified double base" (CMDB)] include an oxidizing solid (such as ammonium perchlorate, or barium nitrate) together with a binder [e.g. HTPB (hydroxy-terminated polybutadiene)], which acts as a fuel.

Solid propellants with NC are divided into three classes based on presence of added energetic compounds. A summary of the major ingredients in some of these propellants is given in Table 3 (U.S. Army 1990). Additional information is available in the Propellant Management Guide published by the U.S. Army Defense Ammunition Center (1998). Single-base propellants contain NC alone as the principal energetic material. Double-base propellants contain NC infused with a liquid organic nitrate, such as NG, which can gelatinize the NC. Triple-base propellants include the two double-base compounds NC and NG along with NQ. NQ adds to the energy

Table 3. Summary of solid propellant classes with common examples.

Type	Uses	Examples	Particle type*	Principal ingredients
Single base	Small arms to cannons	M1 M6 M10	Single- or multi-perforated cylinder Multi-perforated cylinder Flake; Single- or multi-perforated cylinder	NC, 2,4-DNT NC, 2,4-DNT NC, diphenylamine
Double base	Multiple applications including small arms	M2 M5 M8	Single- or multi-perforated cylinder Single-perforated cylinder or flake Perforated increment sheet	NC, NG, ethyl centralite NC, NG, ethyl centralite NC, NG, diethyl phthalate
Triple base	Large caliber guns	M30 M31	Multi-perforated cylinder or hexagonal Multi-perforated cylinder; Single-perforated cylinder or stick	NC, NG, NQ, ethyl centralite NC, NG, NQ, ethyl centralite
Composite	Rockets and missiles	Class 1.3	Single grain	Ammonium perchlorate, Al, HTPB
CMDB	Rockets and missiles	Class 1.1	Single grain	NC, NG, Ammonium perchlorate, Al, HMX, HTPB

* Particle shapes are shown in Figure 3. (From Ch.1 in Jenkins et al. 2007)

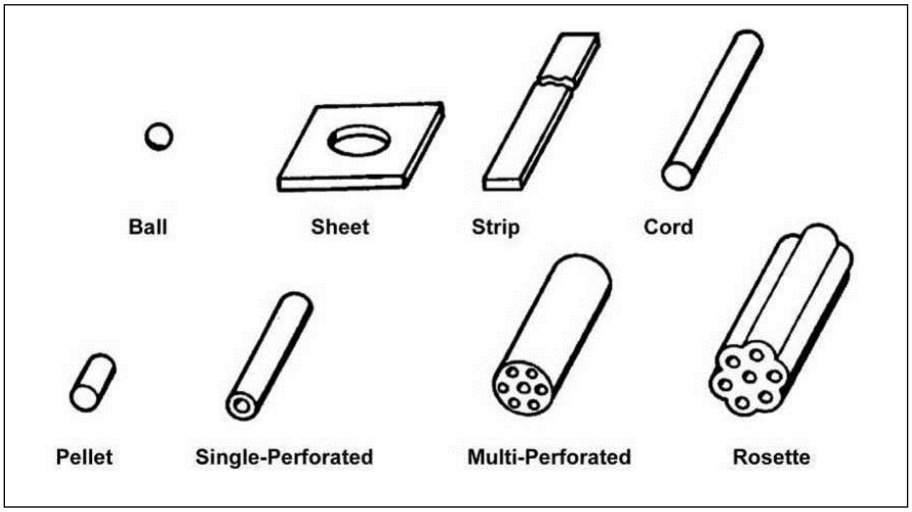
content of the formulation without raising the flame temperature, which reduces erosion in the gun barrel and also reduces flash. NQ tends to be found in the more powerful (higher charge number) artillery and tank propellants.

Three of the stabilizers utilized in propellant formulations are DPA (diphenylamine), ethyl centralite (diethyl diphenyl urea), and akardites (methyl diphenyl urea). DPA is used only in single-base propellants because it is incompatible with the gelatinizing agent NG. NDPA (N-Nitrosodiphenylamine) is the first transformation product of DPA and serves as a stabilizer itself (Jenkins et al. 2007). Double- and triple-base propellant formulations with NG use either ethyl centralite (diethyl-1,3- diphenylurea) or 2-nitrodiphenylamine as a stabilizer. Some double- and triple-base compositions that employ diethylene glycol dinitrate (DEGDN) rather than NG as the gelatinizer use a form of akardite (1-methyl-3,3- diphenylurea) for stabilization.

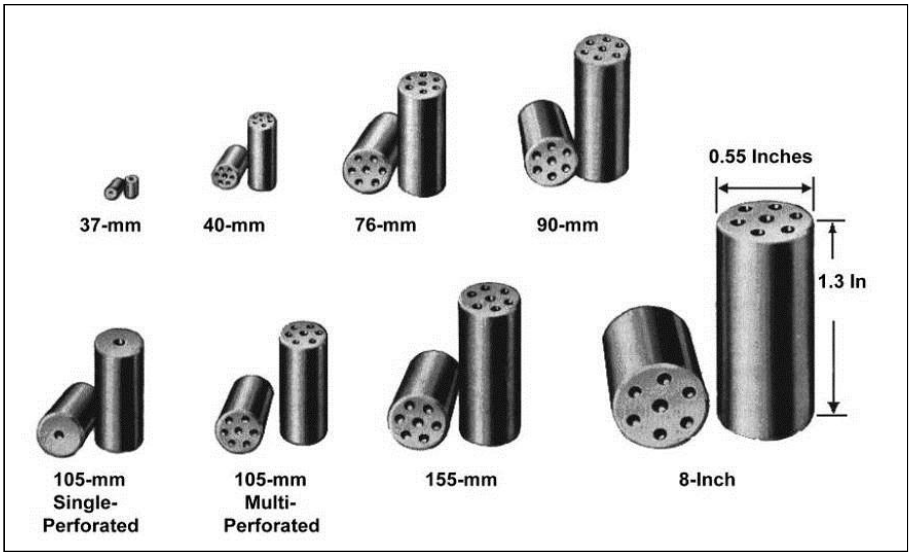
Deterrents or burn rate modifiers are added to propellants used in small arms and large-caliber artillery rounds. They are impregnated into the propellant surface, forming a coating that slows the initial burning rate. Commonly used deterrents include 2,4-DNT, 2,6-DNT, and ethyl centralite. A variety of alkali metal salts are also added to some propellants to help reduce secondary flash and smoke. Other non-energetic binders and plasticizers are included in some propellant compositions to make the grains less brittle and examples include the two esters of 1,2-benzenedicarboxylic (or phthalic) acids—dibutyl phthalate and diethyl phthalate. HTPB is commonly used as a binder for composite and CMDB rocket and missile propellants. A less commonly used binder is triacetin. The propellant grains are also often coated with graphite, a lubricant that prevents the grains from sticking together and dissipates static electricity, avoiding undesired ignitions. Other additives can be included to lower wear of the gun barrel liners such as wax, talc, and titanium dioxide. Tin and lead strips are often added to howitzer and tank propellants as decoppering agents. Copper is the primary ingredient of rotating bands on projectiles.

Grain size and shape

The properties of propellants are greatly influenced by the size and shape of the grains, which include a variety of small spherical balls, plates, or flakes, or in different forms of extruded cylinders or strips (Fig. 3). The propellant burns only on the particle surfaces; therefore, larger grains burn slower. Many of the cylindrical shapes have internal perforations to allow burning from the inside outwards simultaneously with burning from the surface inwards. Some cylinders have a single central perforation; others have multiple perforations, commonly with a central hole surrounded by six others. The size and shape of propellant grains used in a particular munition are balanced in an attempt to regulate the burn so an evenly constant pressure is exerted on the propelled projectile while it is in the barrel.



a. Propellant grain shapes.



b. Example sizes.

Figure 3. Propellant grain shapes and example sizes (From US Army 1990, 1993).

Ignition Train

Propelling charges are ignited through a chain reaction called an ignition train, usually a series of combustibles and explosives arranged according to decreasing sensitivity (Fig. 1b). To activate, a stimulus such as impact, heat, or spark ignites a small primer. In artillery ammunition, the primer then sets fire to the igniter charge, which intensifies the small flame produced by the primer and initiates combustion of the large quantity of propellant. In some cases, igniter charges are also sandwiched between layers of propellant. Commonly used igniter charges include black powder (a combination of potassium nitrate, charcoal, and sulfur) and potassium nitrate by itself.

Primer compositions for explosive fillers are a mixture of primary explosives, fuels, oxidizers, and binders. Primary explosives include lead azide, DDNP (diazodinitrophenol), lead styphnate, tetracene, KDNBF (potassium dinitrobenzofuroxane), and LMNR (lead mononitroresorcinate). Fuels used are metal thiocyanates, antimony sulfide, and calcium silicide. Oxidizing agents include potassium chlorate and barium nitrate.

Primers include three main types: percussion, stab detonator, and electrical. Several percussion and stab detonator priming compositions include the compounds lead styphnate, tetracene, barium nitrate, antimony sulfide, powdered zirconium, lead dioxide, and PETN (pentaerythritol tetranitrate).

The most commonly used electrical primers are the exploding bridge wire, the hot wire bridge, and the film bridge. In an exploding wire detonator, a large current passing through the wire causes it to burst, creating a shock wave that causes the detonation. With this type, no priming composition is needed; the wire is placed directly in a charge of RDX or PETN. Hot wire and film bridges use priming compositions that include potassium chlorate with various combinations of lead mononitroresorcinate, NC, lead thiocyanate, DDNP, charcoal, nitrostarch, titanium, and aluminum.

Summary

Table 4 summarizes the significant ingredients that compose the propellant portion of propelling charges. The greatest mass consists of the oxidizers and energetic binders, ranging between 60 and 90 percent by weight (Miller 1997, MIDAS 2007). Plasticizers and inert binders account for approximately 5 to 25 weight percent. Stabilizers and other compounds (flash reducers, primers, and igniters) account for the remainder, occurring at less than 5 weight percent each.

Table 4. Significant compounds in propellant formulations.

Energetic plasticizers	Stabilizers	Inert binders and plasticizers	Burn rate modifiers
Nitro-based	diphenylamine	dibutyl phthalate	**2,4-dinitrotoluene**
nitrocellulose	2-nitrodiphenylamine	diethyl phthalate	2,6-dinitrotoluene
nitroglycerin	diethyl-1,3- diphenylurea (ethyl centralite)	triacetin	ethyl centralite
nitroguanidine	1-methyl-3,3- diphenylurea (akardite)	wax	
diethylene glycol dinitrate		talc	**Flash reducers**
Oxidizers		titanium oxide	potassium sulfate
ammonium perchlorate		HTPB	potassium nitrate
potassium perchlorate			

Secondary (high) explosives

The most commonly used military high explosives by the United States and Canada today are TNT, RDX and HMX (Fig. 4). In the past, tetryl and ammonium picrate (Explosive D) were also used, but they are not generally found in modern munitions. New compounds are being considered for future use, but these compounds are not currently being used at military training ranges.

The energetic compounds present in the most common DoD explosive formulations are presented in Figure 4 and Table 1. All of these formulations contain one or more of TNT, RDX and/or HMX.

Important physical and chemical properties of energetic compounds

This section presents information on physical and chemical properties that directly affect fate and transport of energetic compounds in the environment. With the exception of NG, the major energetic compounds used by the DoD are solids at ambient temperatures (Table 5) and are deposited on ranges as particles of the solid material (Taylor et al. 2004, 2006). Although NG is a liquid at ambient temperatures, it is used as a component of double- and triple-base propellants associated with the solid polymeric NC. The solubility of these compounds in water varies tremendously from a low of about 4.5 mg/L for HMX to about 4400 mg/L for NQ. Because these compounds usually are deposited as small particles of the energetic compound, the solubility and the rate of dissolution are important in determining the initial fate of the compounds in the environment. At some arid sites, chunks of energetic compounds persist on the soil surface for many decades.

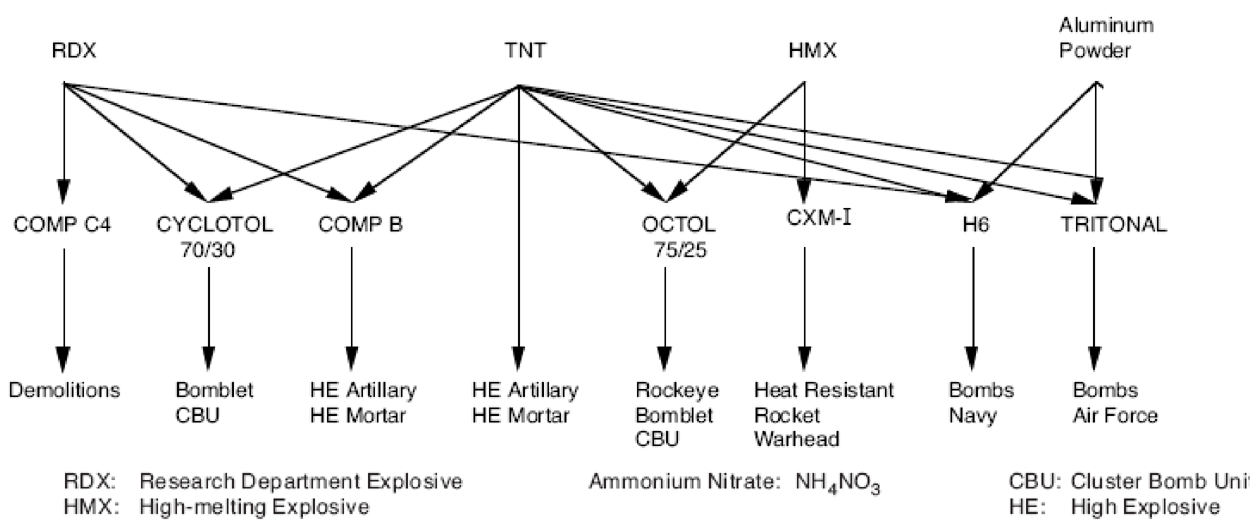


Figure 4. Energetic compounds present in the most common DoD explosive formulations [From Boudeau, (1993) as adapted from AEHA (1985)].

Table 5. Most commonly used physicochemical properties of some explosives utilized by military services (from Sunahara et al., eds. 2009, Sheremata and Hawari 2000, and M.E. Walsh et al 1993).

Common Name	Molecular Weight ($g\ mol^{-1}$)	Melting Point (°C)	Water Solubility[a] at 25 °C ($mg\ L^{-1}$)	Octanol/Water Partition Coefficient ($\log K_{ow}$)	Henry's Law Constant at 25 °C ($atm\ m^3\ mol^{-1}$)	Vapor Pressure at 25 °C (mm Hg)
TNT	227.13	80.1	130	1.6	4.57×10^{-7} [a]	1.99×10^{-6} [a]
2,4-DNT	182.15	71	270	1.98	1.86×10^{-7}	1.47×10^{-4}
2,6-DNT	182.15	64-66	206	2.02		5.7×10^{-4}
2-Am-DNT	197.17	176	42	1.94		4.0×10^{-5}
4-Am-DNT	197.17	171	42	1.91		2.0×10^{-5}
Tetryl	287.17	129.5	75	2.04	2.69×10^{-11}	5.69×10^{-9}
TATB	258.15	ND	32	0.7	5.8×10^{-12}	1.34×10^{-11}
Picric Acid	229.10	121.8	12800	1.33	1.7×10^{-8}	7.5×10^{-7}
NC	10^5–10^6	206 [b]	Insoluble	ND [c]	ND	ND
PETN	316.17	143.3	43*	3.71	1.7×10^{-9}	5.38×10^{-9}
NG	227.11	13.5	1800	1.62	3.4×10^{-6} [a]	2×10^{-4}
EGDN	152.08	-22.3	5200	1.16	2.52×10^{-6}	7.2×10^{-2}
RDX	222.26	205	56.3	0.90	1.96×10^{-11}	4.0×10^{-9}
HMX	296.16	286	4.5	0.17	2.60×10^{-15}	3.3×10^{-14}
CL-20	438.19	260[b]	3.7	1.92	ND	ND
NQ	104.07	239	4400	-0.89	4.67×10^{-16}	1.43×10^{-11}

Note: [a] At 20°C; [b] With decomposition; [c] ND – Not determined;
* This value is uncertain; range of cited values from 2.1 to 43 $mg\ L^{-1}$

Once dissolved or leached from polymeric NC matrices, the tendency of energetic compounds to sorb to soil substrates varies substantially. The octanol/water partition coefficients are often correlated with soil/water partition coefficients for organic compounds and values for these compounds are shown in Table 5. Very low values for compounds such as NQ, HMX, and RDX indicate these substances will not be sorbed strongly to soil surfaces and hence will be more mobile in the environment than others such as TNT or especially PETN. The low soil/water partition coefficients and limited water solubility makes sampling soils in the subsurface problematic. Even when contamination has reached groundwater, the concentrations of RDX, in particular, may be below analytical detection limits in the subsurface soil. The reason for this is because RDX is present mostly within the soil moisture fraction, which is quite small compared to the mass of the soil. More thorough lists of these compounds' physical properties with references for each value are given in McGrath (1995) and Clausen et al. (2006).

Energetic compounds are classified as semi-volatile organics, but because many of them are thermally unstable, they are generally not analyzed using gas chromatography (GC) or gas chromatography/mass spectrometry (GC/MS). This has been a particular problem for analysis of

HMX. Most analyses of energetic compounds in soil and water are conducted using high performance liquid chromatography (HPLC) (US EPA 2006). Because these compounds are not volatile (vapor pressures at 25°C vary from about 10^{-4} to 10^{-15} torr), soil increments containing these chemicals can be combined and processed without loss due to volatilization, a property that has been exploited when collecting, preparing, and subsampling representative samples.

Fate and transport issues

This section is not intended to provide an exhaustive discussion of the research associated with fate and transport of energetic chemicals in the environment; rather, it will introduce the important factors that affect their behavior in this regard. Clausen et al. (2006) provide a detailed discussion of fate and transport issues and energetic chemical physiochemical properties.

The major sources of energetic residues at DoD training ranges are deposits of these chemicals, largely as particles of the energetic formulations. The surfaces of particles deposited on the soil surface are subject to reactions with sunlight (photodegradation) (Taylor et al. 2010). TNT is particularly subject to photodegradation leading to a complex array of reaction products, (Burlinson et al. 1978) that vary in their environmental stability, some of which are highly colored. 1,3,5-TNB (1,3,5-Trinitrobenzene) is the primary stable photodegradation product of TNT in environmental systems. For the solid explosives, photodegradation reactions occur only on the surface, but these products can be washed off by precipitation often producing a halo of reddish brown residue on the soil surface surrounding these TNT-containing particles. Tetryl photolyzes rapidly to N-methypicramide (Kayser et al. 1984). Photodegradation reactions of other energetics are less well studied but thought to be less significant than for TNT or tetryl.

While it is possible that small particles of energetic compounds can be transported in surface runoff, there is little evidence that this is a major mechanism for transport of these residues beyond the source zone at ranges. A more significant mechanism is thought to be dissolution by precipitation and downward transport into soil. Some initial studies on the rates of dissolution of nitroaromatics and nitramines were conducted by Lynch et al. (2001, 2002a, b) using a stirred reactor and by Morley et al. (2006) using non-stirred batch reactors and columns. More recently, Taylor and co-workers (2009) have conducted rainfall simulation experiments with TNT, Composition B, Tritonal, and Octol, both in the laboratory and in outdoor experiments. In addition, Dontsova et al. (Ch. 5 in Jenkins et al. 2007 and Ch. 12 in Jenkins et al. 2008) reported on column experiments evaluating the mobility of propellant related compounds in soil columns.

Once dissolved, RDX and HMX in particular can migrate through the vadose zone and contaminate underlying groundwater aquifers, especially on training ranges that have permeable soils, a shallow groundwater table, and abundant rainfall (Clausen et al. 2004, Jenkins et al. 2001, Martel et al. 2009b, and Chapter 3 in Pennington et al. 2006). TNT and its environmental transformation products have been found in groundwater aquifers below ammunition plants and depots but not thus far at training ranges, with the exception of one well in the impact area at Massachusetts Military Reservation (MMR; Clausen et al. 2004). However, TNT does not mineralize in the environment either aerobically or anaerobically, but TNT is environmentally transformed to several isomers of monoaminodinitrotoluene (2AmDNT and 4AmDNT). These compounds are more mobile in the environment than TNT, but they can chemically bind to natural organic matter in soils and become immobilized (Thorn et al. 2002). RDX and HMX do not degrade aerobically to any extent in surface soils, but they can be transformed to mono (and perhaps poly) nitroso compounds in the subsurface under reducing conditions (McCormick et al. 1981, Hawari et al. 2001).

Another energetic chemical thought to be mobile in the environment is ammonium picrate (Explosive D). It was used during the first half of the 20th century primarily in Naval bombs, rockets, and armor-piercing shells. Picric acid (2,4,6-trinitrophenol) was also used during this period for grenades and mines. Both picric acid and ammonium picrate dissociate into picrate anion in aqueous solution. The solubility of picrate is very high, about 10 g/L, and because it is an anion it is very mobile in the soil. Much less research has been conducted on these chemicals because they are no longer in use by the US DoD. Kayser and Burlinson (1988) found that picrate migrated rapidly through four test soils in lysimeters and it was observed in a groundwater sampling well at the Louisiana Army Ammunition Plant (Jenkins, personal communication). Army and Naval munitions containing ammonium picrate and picric acid were known to have been used at MMR. Extensive groundwater sampling conducted at MMR did not identify the presence of these compounds (Clausen 2005). The relevance of this observation to other military installations is unknown since groundwater sampling has not been conducted in the impact area elsewhere. Apparently, picrate can also be transformed to picramic acid (2-amino-4,6-dintrophenol) due to microbial activity under anaerobic conditions.

Tetryl hydrolyzes in aqueous solution and the products are pH dependent. Under acidic conditions the major organic byproducts are picric acid and N-methylpicramide; under basic conditions the products were methylnitramine and the picrate anion (Kayser et al. 1984). Harvey et al. (1992) studied the biotransformation of tetryl in soil and concluded that the rate was very rapid and the product was N-methylpicramide.

Microbial degradation of nitroglycerin has been studied by Wendt et al. (1978). Breakdown occurred stepwise resulting first in the dinitrate isomers followed by the mononitrate isomers. The two dinitrate isomers have been observed in soils from a small arms firing range (Ch. 8 in Jenkins et al. 2008). The rate of degradation in soil is rapid in most soils (Jenkins et al. 2003). Using saturated columns, Dontsova et al. (Ch. 12 in Jenkins et al. 2008) found that in the absence of degradation, NG was mobile in soil columns, but was more retarded in its movement than NQ, that did not appear to be degraded in soils. Diphenylamine, however, was both retained and degraded in soil columns indicating that it would not be expected to penetrate soils to groundwater (Ch. 5 in Jenkins et al. 2007).

Residue deposition at training ranges

Propellant residues at firing points

Numerous experiments have been conducted on snow covered ranges to estimate the mass of energetic residue deposition at firing points, and from live-fire and blow-in-place detonations. Snow covered surfaces prevent cross contamination with past activities and provide a visual footprint where residues are deposited (Jenkins et al. 2002). In addition to energetic residues deposited at firing points other materials such as phthalates and N-nitrosodiphenylamine have been observed (Clausen et al. 2004).

The mass of propellant residues deposited was measured for artillery and mortar firing (M.R. Walsh et al. 2005a, b, 2006; Hewitt et al. 2003; M.E. Walsh et al. 2004), for several different shoulder-fired rockets (M.R. Walsh et al. 2009, Chapter 4 in Jenkins et al. 2008), one type of tank (Ch. 6 in Jenkins et al. 2008), and for the common military small arms (M.R. Walsh et al. 2007a, Faucher et al. Ch 5. in Jenkins et al. 2008). Measurements concentrated on the mass of NG or 2,4-DNT associated with the particles of NC deposited, and not NC itself. NC in soil is not thought to pose health risks, but may retain ignitable characteristics for long periods of time.

To make these measurements, surface snow was collected and the mass of NG and/or 2,4-DNT was determined in both the snowmelt and the filtered soot present in the snow (M.R. Walsh et al. 2007b). The total mass of these residues on a per-round-fired basis is presented in Table 6. The very small amount of residue produced from firing the 155-mm howitzer is consistent with the very low concentrations found for soil samples collected at 155-mm firing points (Ch. 3 in Jenkins et al. 2007). The large mass of residue deposited for shoulder-fired anti tank rockets (M.R. Walsh et al. 2009) is also consistent with the high concentrations of NG observed for surface soil samples at these ranges (Jenkins et al 2004b). Residue deposition from small arms is proportionally very large compared to the initial mass of propellant in the cartridge, but not surprising based on the short length of the barrel and forensics, i.e., powder burns on hands and clothing (M.R. Walsh et al. 2007a).

In most cases, the residue is deposited close to the firing position. For small arms, M.R. Walsh et al. (2007a) estimated that 99% of the residue is deposited within 5 m of the firing line for pistols, 10 m for rifles and small machine guns, and 20 m for 50-caliber machine guns. Deposition extends out to 50 m behind where shoulder-launched rockets are fired (M.R. Walsh et al. 2009, Ch. 3 in Jenkins et al. 2007), and 10 to 20 m in front. By far the greatest residue deposition is to the rear at these firing positions for antitank rockets. Downrange deposition is somewhat

Table 6. Mass of NG or 2,4-DNT deposited at firing points per round fired for various weapon systems.

Weapon System	Propellant	Constituent	Rounds fired	Residues/ round (mg)	Downrange Distance for deposition (m)	References
Howitzers						
105-mm	M1-I & II	DNT	71	34	ND [1]	M.R. Walsh et al. 2009
105-mm	M1	DNT	22	6.4	ND	M.R. Walsh et al. in Ch 4 Jenkins et al. 2007
155-mm	M1	DNT	60	1.2	ND	M.R. Walsh et al. 2005a
Mortars						
60-mm	Ignition cartridge	NG	40	0.09	12 m	M.R. Walsh et al.2006
81-mm	M9 (illuminator)	NG	61	1,000	50 m	M.R. Walsh et al.2006
120-mm	M45	NG	40	350	ND	M.R. Walsh et al. 2005b
Shoulder-fired rocket						
84-mm Carl Gustav	AKB 204/0	NG	39	1055	30 m [2]	Thiboutot et al. Ch 4 in Jenkins et al. 2008
84-mm AT4	AKB204	NG	5	20,000	50 m [2]	M.R. Walsh et al.2009
Tank (Leopard)						
105-mm	M1	DNT	90	6.7	ND	Ampleman et al. 2009
Grenade						
40-mm (HEDP)	M2	NG	144	76	5 m	M.R. Walsh et al. 2010b
40-mm (TP)	F15080	NG	127	2.2	5 m	
Small Arms						
5.56-mm Rifle	WC844	NG	100	1.8	10 m	M.R. Walsh et al. 2007a
5.56-mm MG	WC844	NG	200	1.3	30 m	
7.62-mm MG	WC846	NG	100	1.5	15 m	
9-mm Pistol	WPR289	NG	100	2.1	10 m	
12.7-mm MG (.50 cal)	WC860 & WC857	NG	195	11	40 m	

[1] ND Downrange distance for deposition was not determined.

[2] Major deposition is behind the firing line for shoulder-fired rockets, but downrange for other types of munitions.

greater for 105-mm artillery and tanks than for 155-mm artillery. For propellant residues, it is possible to estimate the mass of either NG or 2,4-DNT that would be deposited at firing points if the total number of rounds of a given type fired is known. In the past, detailed firing records needed to make this type of estimate were seldom maintained, but current record keeping may allow this type of estimation in the future. Thus, the downrange distance for establishing sampling areas can be established based on the measured depositional distances obtained in these studies.

After training with various large caliber weapon systems like mortars and artillery, there is often a large quantity of unused propellant remaining because sufficient propellant is supplied to fire the weapons at maximum distance, and often that is not desired or possible. The general practice is to destroy this unused material in the field by piling up the material or laying it in a line on top of the soil and igniting it. Sometimes it may be collected and burned in a burning pan. Several studies have been conducted to assess the residue remaining from these practices under different environmental conditions (M.R. Walsh et al. 2010a). Propellant burns were conducted in summer and winter, on wet and dry soil, snow, and frozen soil. The mass of NG or 2,4-DNT remaining after the burn was measured and compared to that present in the initial amount of propellant burned (Table 7). Propellant residues recovered in burn areas were large compared with those deposited from firing activities with the same propellant and were deposited over a smaller surface area resulting in higher concentrations in the soil. These results are preliminary and residue loading is quite variable. It appears to be influenced by surface condition (seasonal conditions) and the type or configuration of the propellant loads.

Table 7. Mass of initial propellant constituents recovered (%) after expedient propellant burning (M.R. Walsh et al. 2010a).

Test condition for burn	Propellant type	Mass recovered as % of initial mass in propellant
Summer (dry soil)	M1	0.95
Summer (wet soil)	M1	0.99
Winter (frozen soil)	M45	5.2
Winter (Snow)	M45 M9	18 1.7

Explosives residues at impact areas

When projectiles reach the impact area and the explosive reaction goes to completion as designed, the round is said to have detonated at high order. When a malfunction occurs in some way so that the reaction is only partially completed, the round is said to have detonated low order or has undergone a partial detonation. The total explosive present in a given munition is referred to as the net explosive weight (NEW).

The mass of explosives residues deposited when a round detonates high order was estimated for a variety of munitions including: hand grenades (Hewitt et al. 2005b), mortars (Hewitt et al. 2005b, M.R. Walsh et al. 2005b), and artillery rounds (M.E. Walsh et al. 2004, M.R. Walsh et al. 2005a). The estimates for mortars and artillery were obtained from live fire tests and those from the hand grenades were from grenades thrown in the normal manner. Table 8 is a summary of the estimated deposition per round that detonated at high order. Overall, the consumption of the high explosives present in the warheads of these rounds was always greater than 99.99% for all the

Table 8. Mass of explosives residue deposited from high-order live fire detonations of Composition B- filled rounds.

Weapon System	Analyte	Net Explosive Weight (g)	Average Mass Deposited (µg)	Plumes sampled	Percent deposited	Reference
Mortars						
60-mm	RDX	215	94	11	3 x 10^{-5}	Hewitt et al. 2005b
	TNT	140	14	11	1 x 10^{-5}	
81-mm	RDX	570	8500	5	2 x 10^{-3}	Hewitt et al. 2005b
	TNT	370	1100	5	3 x 10^{-4}	
120-mm	RDX	1794	4200	7	2 x 10^{-4}	M.R. Walsh et al. 2005b
	TNT	1166	320	7	2 x 10^{-5}	
Hand grenade						
M67	RDX	110	25	7	2 x 10^{-5}	Hewitt et al. 2005b
	TNT	72	ND*	7	< 10^{-5}	
Howitzer						
105-mm	RDX	1274	95	9	7 x 10^{-6}	Hewitt et al. 2003
	TNT	812	170	9	2 x 10^{-5}	
155-mm	RDX	4190	300	7	5 x 10^{-6}	M.R. Walsh et al. 2005a
	TNT	2730	ND	7	< 10^{-5}	
	*ND – Not Detected					

munitions tested when the rounds functioned properly; thus the mass of residues deposited is quite small when rounds detonate as designed and result in a high-order detonation.

Tests were also conducted to simulate the blow-in-place detonations used to destroy surface UXO (unexploded ordnance) on many ranges (Pennington et al. 2006, M.R. Walsh et al. 2007b). These items are detonated on active ranges by military EOD (Explosive ordnance disposal) teams using C4 (Composition 4) demolition explosive. On closed ranges, FUD (Formerly Used Defense) sites, and MMRP (Military Munitions Response Program) sites, the destruction of UXO is usually conducted by private UXO technicians using other types of detonation explosives because they do not have access to military C4 (Pennington et al. 2006). These contractors use a variety of initiators including oil well perforators that contain a small amount of either RDX or PETN. Unlike live fire rounds that detonate from the inside out, blow-in-place detonations take place from the outside in and do not use the detonation train built into the munition. Table 9 summarizes the results obtained for C4-initiated blow-in-place detonations of a variety of munitions that detonated at high order. Overall, the deposition from high order detonations during blow-in-place of duds is higher than from similar rounds that detonate as designed, but still much lower than from low-order detonations as described below. Pennington et al. (2006) also investigated the deposition of residues for ordnance detonated with a variety of donor charges including TNT blocks, C4, shaped charges, and binary explosives (Fig. 5). Results varied for different munition/donor

Table 9. RDX deposition from blow-in-place of military munitions using C4 demolition explosive.

Detonation type	Number of trials	Mean RDX deposition (mg)	(%)	Reference
C4 (alone)	11	20	3.9×10^{-3}	Pennington et al. 2006
Mortars				
60-mm	35	0.093	8.1×10^{-5}	Pennington et al. 2006
81-mm	11	95	2.2×10^{-2}	Pennington et al. 2006
Artillery				
105-mm	7	41	2.9×10^{-3}	Pennington et al. 2006
155-mm	28	13	3.1×10^{-4}	Pennington et al. 2006
Hand grenade (M-67)	7	26	2.4×10^{-2}	Hewitt et al. 2003

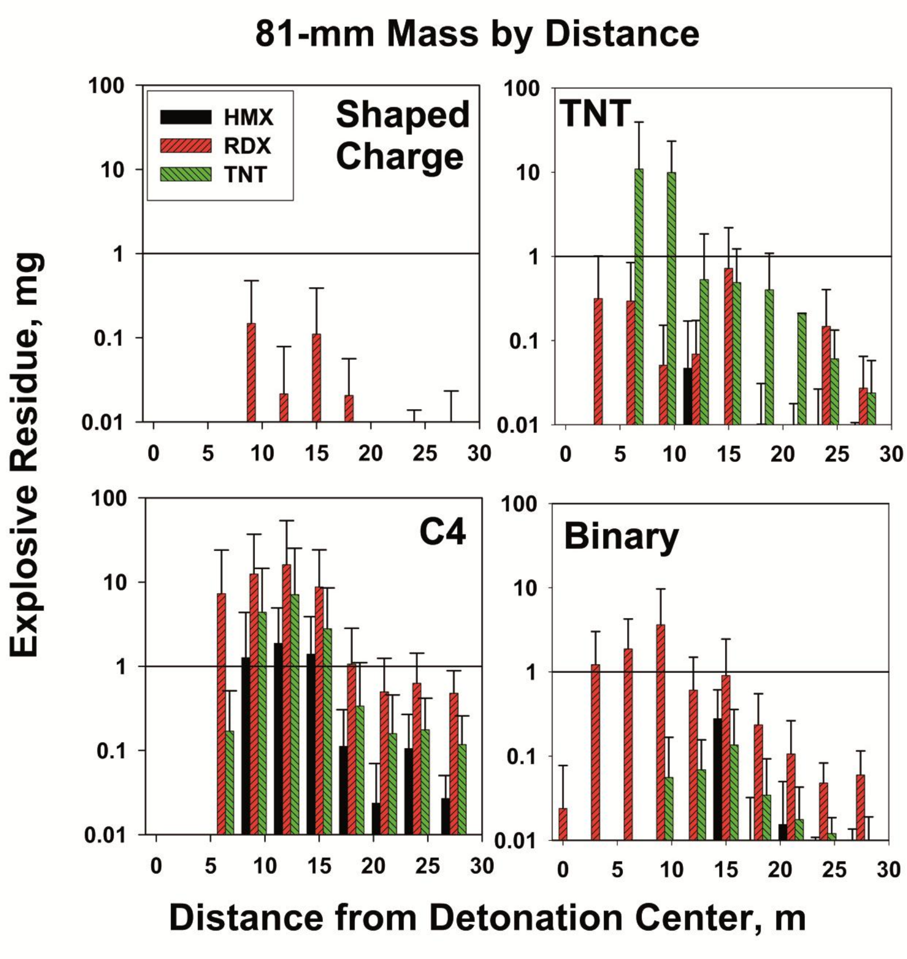


Figure 5. Mass of HMX, RDX, and TNT deposited with distance for each donor charge tested with the 81-mm mortar rounds (from Pennington et al. 2006).

charge combinations, but donor charges must be sufficient in size to ensure that a high order detonation of the UXO item occurs. Residue deposition was detected as far as 30 m from the detonation and contained contributions from the explosive contained in the UXO item and the donor charge. RDX predominates in the residue from detonations of items containing Composition B and from detonations using C4.

A percentage of fired rounds undergo low-order detonations. The frequency of occurrence has been estimated by Dauphin and Doyle (2000) and varies substantially from one munition type to another. To estimate the mass of energetic compounds remaining from low-order rounds, detonation tests were conducted at Blossom Point, Maryland on a raised table. The mass of compounds deposited was obtained after sweeping the residue from tarps covering the surrounding area and weighing the residue (Pennington et al. 2006). Five types of munitions were studied: 60-mm, 81-mm, and 120-mm mortars containing Composition B, 105-mm howitzer projectiles containing Composition B, and 155-mm howitzer projectiles containing either TNT or Composition B. Table 10 summarizes the results of this work with percent of original mass of explosives deposited ranging from 27 to 49%. This is an enormous mass of residue compared with that deposited from high-order detonations (Table 8). For a rule of thumb, it takes about 10,000 to 100,000 high-order detonations to deposit the same mass of residue as that from one low-order detonation of the same type of munition. Clearly from a management perspective, these low-order detonations constitute the main source of explosives residues at impact areas.

Observations from on-range investigations indicate that low-order detonations are not uncommon events for many munitions. Because low-order detonations are the major source of residues at impact areas, and the frequency of their occurrence is hard to predict, the mass of residues deposited at impact areas is difficult to estimate with any degree of accuracy (Dauphin and Doyle 2000). Based on numerous observations of live-fire training exercises, published low-order rates from range records are not a reliable source of frequency and the rates vary substantially from exercise to exercise. For example, of 160 120-mm mortar rounds fired, eight did not

Table 10. Mass of explosives residue deposited from low-order detonation tests (from Pennington et al. 2006, Table 9-1).

Ordnance item	Explosive fill	Mass of explosive in round (g)	Percent deposited
Mortars			
60-mm	Composition B	191	35
81-mm	Composition B	726	42
120-mm	Composition B	2989	49
Howitzer			
105-mm projectile	Composition B	2304	27
155-mm projectile	TNT	6985	29

detonate (duds) and four produced low-order detonations (M.E. Walsh et al. 2010). The dud and low-order rates for this ordnance were reported to be 4.7 and 0.1%, respectively (Stewart et al. 2006). From observation, these dud and low-order events often are not recorded. Thus, tabulated range record rates underestimate malfunctions, confounding efforts to predict the mass of residue deposition on live-fire impact ranges. The surface area over which low-order detonations of the various types of munitions deposit residues is still uncertain, i.e. are they co-located with high densities of craters, UXO, and metallic debris or more random in distribution, although some research to address this topic is underway. The resulting distribution at impact areas can be described as distributed point sources, complicating both site characterization as well as many approaches to remediation or best management practices to destroy residues on site.

Accumulation of energetic residues at various types of DoD ranges

Field studies have been conducted at over 30 military installations in the United States and Canada (Fig. 6) to identify the energetic residues present in the surface soils to understand the distributions of these residues on various types of training ranges (Jenkins et al. 2006a). Ranges

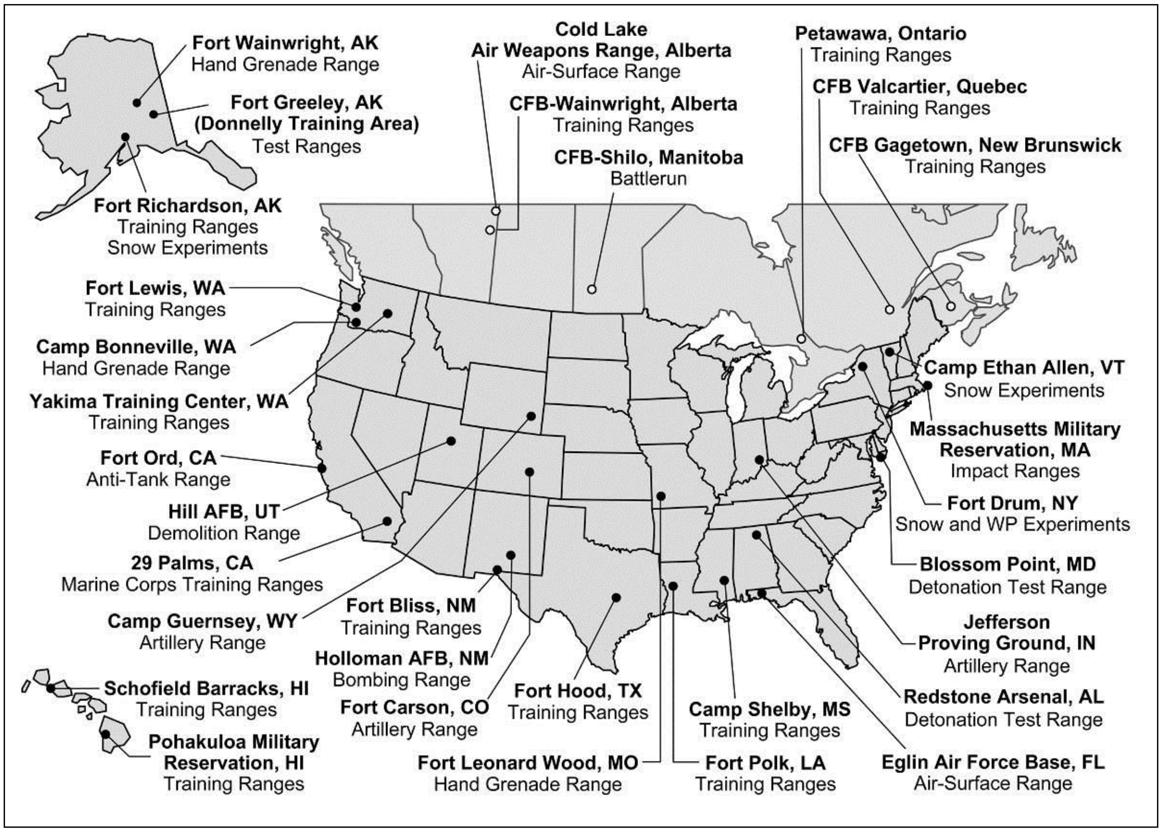


Figure 6. Field experiment sites at various U.S. and Canadian test and training ranges.

investigated included hand grenade, rifle grenade, antitank rocket, demolition, tank firing, mortar, artillery, bombing, demolition, small arms, and demolition ranges. Most ranges include an area where the weapon is fired and a separate impact area where detonations occur. Generally, energetic residues at the firing points are associated with propellants, whereas residues at the impact areas are compounds related to high explosives in the munition warheads, or white phosphorus (WP) from smoke rounds. Here we summarize the results of these studies. The sampling and analytical methods used to obtain these results evolved over time and are discussed elsewhere in this document.

Hand grenade ranges

Hand grenade ranges are only a few hectares in size and, because of the large number of individual detonations in a small area, the surface is usually bare or poorly vegetated (Fig. 7). These ranges often have several training bays from which soldiers throw grenades. Most of the detonation craters lie at distances between 15 and 35 m from the throwing pits. Thus compared with other types of ranges, only a very small area is subject to residue deposition. The most commonly used item at these ranges is the M67 fragmentation grenade. Its explosive charge is 185 g of Composition B. This means that compounds expected include RDX, TNT, HMX, and wax (Table 1), along with a few other isomers of TNT and DNT (Leggett et al. 1977).

Soil samples were collected at 11 active and two closed hand grenade ranges (Table 11). Concentration ranges of the major residue chemicals (RDX, TNT, and HMX) fell into two groups: one had concentrations generally less than 0.12 mg/kg and the other had concentrations

Figure 7. Old hand grenade range at Ft. Lewis, Washington.

generally above 1 mg/kg (Jenkins et al. 2006a). Live-fire studies indicate grenades that detonate high order do not deposit sufficient residues to account for the ranges with higher residue concentrations. However, remnants of grenades that did not completely detonate were found at these ranges (Fig. 8). These grenades either had undergone partial (low order) detonations or had been duds that were blown in place and did not fully detonate. When these types of detonations occur, much higher levels of residues are deposited, accounting for the higher concentrations of residues found at some ranges. In most cases, the highest concentrations of energetic compounds were in the top few cm of soil. These compounds can be deeper in the soil profile, though, if deep craters were allowed to develop before the surface was reconditioned.

Antitank rocket range

Impact areas

Antitank rocket ranges are direct fire ranges, up to several hundred hectares in size. They typically have only low-growing vegetation due to the necessity of maintaining a line of sight for training (Fig. 9). Targets are often derelict armored vehicles placed downrange at distances of 100 m or more from the firing points. The weapons fired most often at these ranges are the 66-mm M72 light anti-armor weapon (LAW) and the 84-mm AT4 rocket. These munitions contain

Table 11. Summary of results for energetic compounds detected in surface soils at hand grenade ranges.

Installation	Year sampled	Samples analyzed†	Mean concentration (mg/kg)					
			HMX	RDX	TNT	TNB	4ADNT	2ADNT
Fort Lewis, WA[1,3]	2000	23*	1.8	7.5	9.3	0.05	0.15	0.13
	2001	5** (50)	1.0	4.4	1.5	ND***	ND	ND
Fort Richardson, AK[1,3]	2000	27*	0.02	0.08	0.03	ND	0.01	0.01
Camp Bonneville, WA[2]	2000	48*	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Fort Leonard Wood, MO[1]	2001	18** (30)	0.19	0.45	<0.01	<0.01	<0.01	<0.01
CFB-Shilo, Manitoba[1,4]	2001	15** (20)	0.05	0.71	0.06	<0.01	0.02	0.02
Fort Wainwright, AK[1]	2002	25** (1,5,10,20,40)	2	11	1.2	0.15	ND	ND
Schofield Barracks, HI[1]	2002	3** (30)	9.1	51	36	0.28	0.40	0.03
Pohakuloa Training Center, HI[1]	2002	7** (30)	0.53	5.6	0.78	<0.01	<0.01	<0.01
CFB-Gagetown, New Brunswick								
Old Castle Range[2,5]	2002	5** (30)	0.02	0.12	0.12	<0.01	<0.01	<0.01
New Castle Range[1,6]	2002	5** (30)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
New Castle Range[1,7]	2003	15** (25)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Fort Polk, LA[1]	2003	2** (30)	<0.01	0.01	<0.01	<0.01	<0.01	<0.01
CFB-Petawawa, Ontario[1]	2004	9** (25,100)	0.18	0.65	0.16	<0.01	<0.01	<0.01

† * Discrete samples; ** Multi-increment samples with (n) increments per sample; *** ND – Not determined

1 Active ranges	5 Pennington et al. 2004
2 Closed ranges	6 Thiboutot et al. 2003
3 Jenkins et al. 2001	7 Thiboutot et al. 2004
4 Ampleman et al. 2003a	

Figure 8. Hand grenades that did not completely detonate.

Figure 9. View from firing point towards targets at the Arnhem anti-tank range, CFB-Valcartier, Quebec.

M7 double-base propellant; the warhead contains octol and a small amount of RDX in the booster charge. M7 propellant contains 54.6% NC, 35.5% NG, 7.8% potassium perchlorate, 0.9% ethyl centralite, and 1.2% carbon black. Octol includes 70% HMX and 30% TNT. At some ranges, practice rounds are fired that contain propellant but do not contain Octol (subcal rounds).

Field experiments were conducted at seven active antitank ranges and one closed range. The primary residue detected at antitank rocket impact areas is HMX; concentrations in surface soils adjacent to targets are generally in the hundreds of mg/kg (Table 12). Even though octol contains 30% TNT, TNT is generally only present at about 1/100th that of HMX in the soil at these ranges. Also present at detectable levels are RDX and two environmental transformation products of TNT (4AmDNT, and 2AmDNT), but the concentrations are always several orders of magnitude lower than that of HMX. The level of HMX in the soil declines as the distance from the target increases (Fig. 10). Observations indicate LAW rockets frequently rupture upon impact without detonating, thereby depositing crystalline explosive over the soil surface (Fig. 11). This deposition is thought to be the major source of explosives residues at these impact areas.

Because HMX has a low aqueous solubility (about 4–5 mg/L at 25°C), it tends to accumulate on the surface; the more soluble TNT (about 150 mg/L) dissolves and undergoes environmental transformations. Amino transformation products of TNT can covalently bind to soil organic matter and become immobilized (Thorn et al. 2002). The HMX that slowly dissolves does not

Table 12. Concentrations of energetic compounds detected in surface soils adjacent to targets at antitank rocket ranges.

Installation†	Year sampled	Samples analyzed††	Mean concentration (mg/kg)				
			HMX	RDX	TNT	4ADNT	2ADNT
CFB-Valcartier, Quebec [1,3,4]	1995	16*	803	4.6	24	<0.1	<0.1
	1995	5*	399	0.76	3	<0.1	<0.1
	1996	20*	662	<0.1	4	<0.1	<0.1
	2003	4**(30)	898	2.8	7	<0.1	<0.1
WATC-Wainwright, Alberta [1,3]	1997	11*	987	5.3	126	<0.1	<0.1
Fort Ord, CA [2,5]	1997	8***	307	0.25	0.2	0.69	0.55
Camp Edwards, MA [1,7]	1999	11**(5)	35	22	2.1	0.14	0.18
CFB-Gagetown, New Brunswick [1,4]	1998	10	680	<1	4	<0.1	<0.1
	2002	5**	874	0.5	6	0.8	0.7
	2003	8**	489	0.5	2	0.4	0.5
Yakima Training Center, WA [1,6]	2001	6**(30)	23	0.8	0.04	0.05	0.12
CFB-Petawawa, Ontario [1]	2004	3**(50)	745	0.32	73	<0.1	<0.1

† Impact areas at Pohakuloa and Fort Bliss anti-tank ranges were not sampled.

†† * Composite samples; ** Multi-increment samples with (n) increments per sample; *** Discrete samples

[1] Active ranges — [2] Closed range — [3] Thiboutot et al. 1998 — [4] Jenkins et al. 2004a — [5] Jenkins et al. 1998 — [6] Pennington et al. 2002 — [7] Ogden 2000

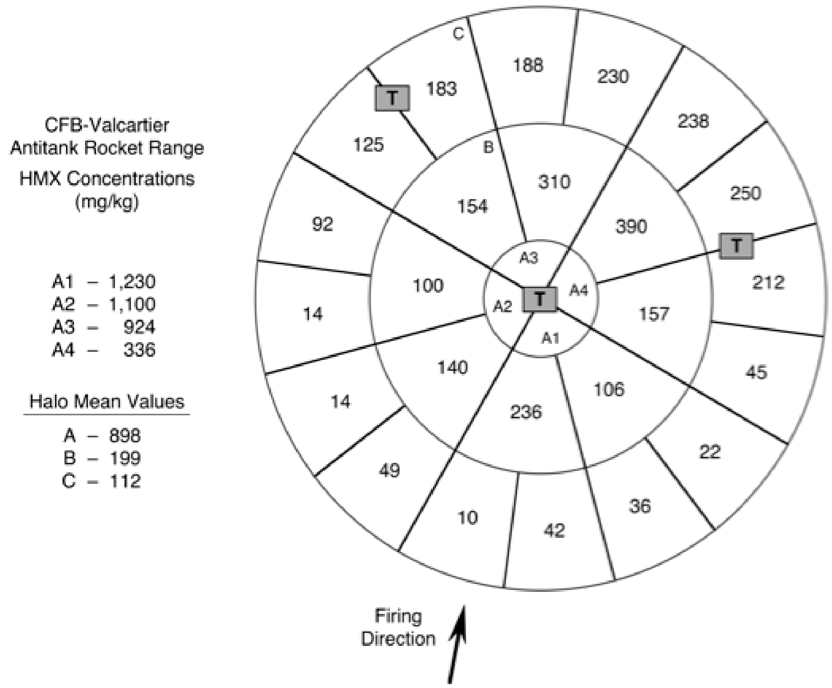


Figure 10. Distribution of HMX residues surrounding target vehicles at Valcartier, using an older-stylesampling design. Target positions are indicated by gray-shaded rectangles marked with a "T." Sampling halos were divided at radii of 5 m (A), 5 –15 m (B), and 15 –25 m (C).

Figure 11. Ruptured LAW rocket at CFB-Valcartier, amber solid is octol, the color results from photolysis of the TNT component.

strongly interact with soils and can be carried through the vadose zone to underlying groundwater aquifers (Martel et al. 2009b).

Many anti-tank rockets are propelled all the way to the target, consequently propellants can still be present when these rockets detonate upon impact. Small pieces of propellant are thereby spread over the soil surface in the area surrounding the targets. These residues are often visible and NG has been detected at the impact areas at concentrations as high as 23 mg/kg. This may also be due to the poor burn characteristics of the propellant, as well.

Firing point areas

Sampling has been conducted at seven antitank rocket range firing points (Table 13). In all cases, NG was the primary energetic compound detected; however, only a few samples were

Table 13. Summary of results for nitroglycerin (NG) near firing points at active anti-tank rocket ranges.

			Mean NG concentration (mg/kg)								
			Position in front (m)					Position behind (m)			
Installation	Year sampled	Samples analyzed†	0–10	10–20	20–30	30-40	40-50	0–10	10-20	20–30	30–40
Yakima Training Center, WA[1]	2001	2 (30)	3	—*	—	—	—	—	—	—	—
Schofield Barracks, HI[2]	2002	4 (30)	—	—	—	—	—	1200	9.4	—	—
CFB-Gagetown, New Brunswick[3,4]	2002	4 (30)	176	65	—	—	14	1130	—	—	—
	2003	15 (30)	160	160	87	55	12	4700	2320	380	84
Fort Bliss, NM[5]	2002	10 (30)	1	0.5	<0.1	—	—	1	—	—	—
CFB-Valcartier, Quebec[6]	2003	13 (30)	NS	4.2	0.8	0.1	0.4	910	490	104	—
CFB-Petawawa, Ontario[7]	2004	8 (40)	—	—	—	—	—	2360	380	—	—
Ft. Lewis, WA											
Practice subcal area[8]	2006	16 (25)	—	—	—	—	—	632	175	82.4	13.0
Live fire area[8]	2006	8 (25)	—	—	—	—	—	936	206	—	—
Practice subcal area[9]	2009	4 (100)	—	—	—	—	—	860	—	—	—
Live fire area[9]	2009	4 (100)	—	—	—	—	—	1870	—	—	—
Camp Edwards, MA[10]											
TOW missile	1999	3 (5)	6.6	—	—	—	—	40	—	—	—
Dragon	1999	2 (5)	<0.12	—	—	—	—	<0.12	—	—	—
90-mm recoilless rifle	1999	2 (5)	2.9	—	—	—	—	13	—	—	—
LAW rocket	1999	10 (5)	5.7	—	—	—	—	268	—	—	—

† Number of multi-increment samples with (n) increments * — No sample collected

1 Pennington et al. 2002
2 Hewitt et al. 2004
3 Thiboutot et al. 2003
4 Thiboutot et al. 2004
5 Pennington et al. 2003
6 Jenkins et al. 2004a
7 Brochu et al. 2009
8 Jenkins et al. 2007
9 Roote 2010
10 Ogden 2000

analyzed for perchlorate. NG concentrations in surface soil samples from 0 to 25 m behind the firing line at Canadian Forces Base (CFB)–Valcartier were generally in the hundreds of mg/kg; whereas, concentrations between the firing line and the target were generally much lower (Fig. 12). In 2003 at CFB–Gagetown, soil cores were collected at a gravelly location behind the firing line at an antitank rocket range to depths reaching up to 63 cm below the surface (Ch. 4 in Pennington et al. 2005). In one soil profile, NG concentrations declined from 20 mg/kg in the surface 0–5-cm depth to 6.4 mg/kg at the 20–27-cm interval, and further declined to a concentration

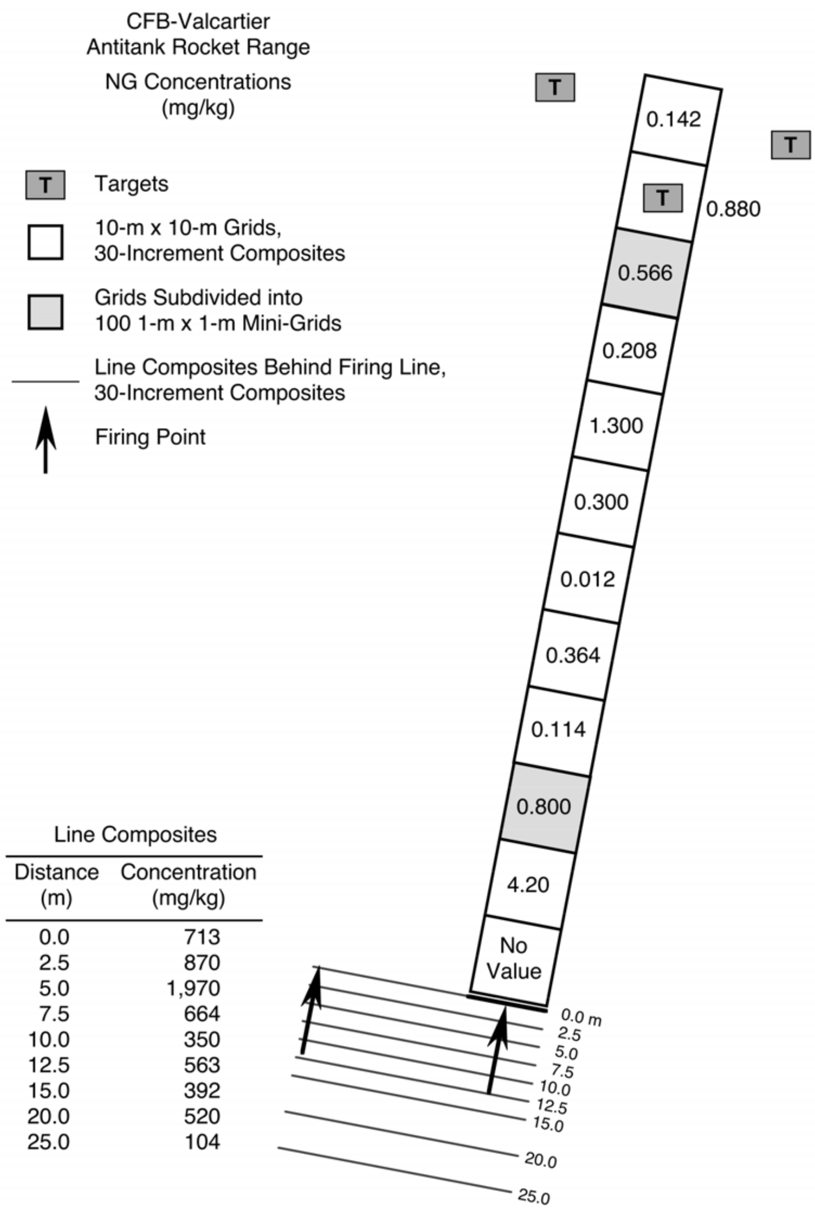


Figure 12. Concentration of NG in composite soil samples collected in front of and behind the Arnhem rocket firing line at CFB–Valcartier.

of about 0.2 mg/kg from 40 to 60 cm deep. Thiboutot et al. (2003) found surface concentrations of NG as high as 11,300 mg/kg at this site. NG availability for dissolution is a function of its rate of release from the solid propellant residue and the amount of water in contact with the residues.

Perchlorate was generally either not determined in soil samples from antitank ranges or was not detected. Perchlorate is so soluble in water and mobile in soil that surface accumulation apparently does not occur as it does for nitroglycerin. Perchlorate is present in some antitank propellants, however, and it has been found in ground water plumes below the antitank firing range at CFB–Valcartier, QC (Fig. 13).

Artillery, tank, and mortar ranges

Artillery ranges are the largest training ranges used by the Army, covering areas of hundreds of square km, or about 40,000 square km throughout the country (DSB 2003, Fig. 14). Firing positions are often arranged around the circumference of the range with firing fans leading into the impact areas (Fig. 15). In the past, fixed firing points were used; with modern mobile artillery, firing activities have become more de-centralized as training has changed to support a “shoot and scoot” strategy. Once fired, artillery and mortar rounds can travel several km before impacting and detonating in the vicinity of targets. The flight path takes these rounds over an area referred

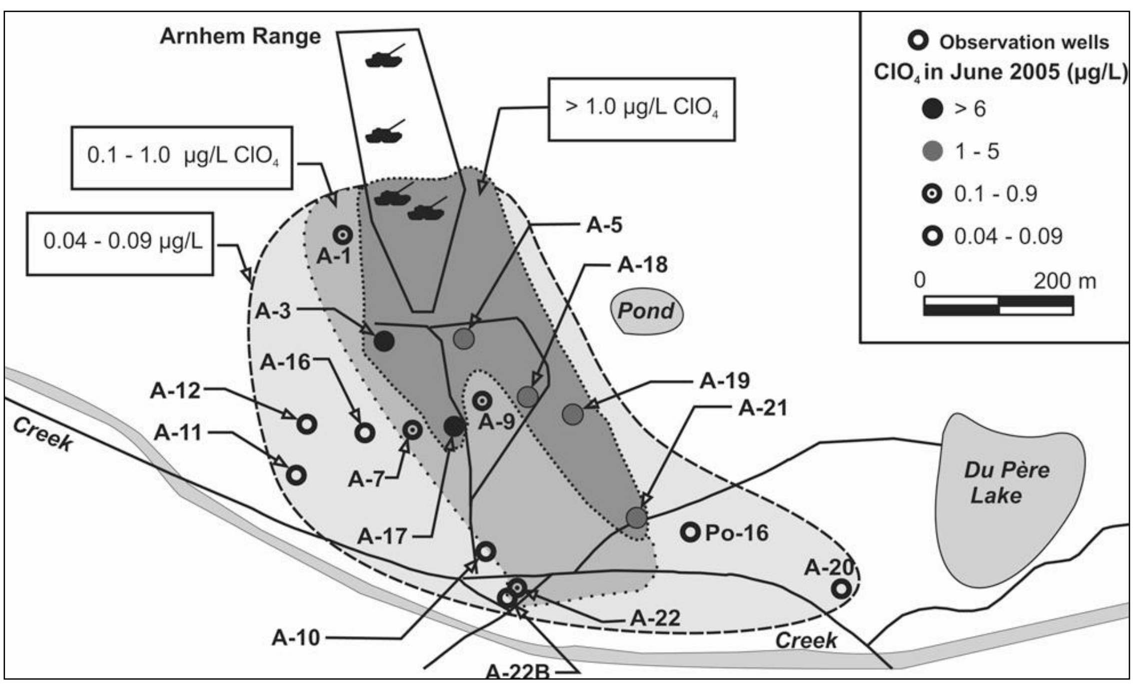


Figure 13. Dissolved perchlorate plume in ground water at CFB–Valcartier, June 2005. Wells A-11, A-12 and A-16 probably show the contribution from another perchlorate source (from the present three targets, only two have been shown) (from Martel et al. 2009b).

a. Ft. Bliss, New Mexico

b. Ft. Lewis, Washington

c. Ft. Richardson, Alaska

d. 29 Palms, California

Figure 14. Examples of artillery range impact areas.

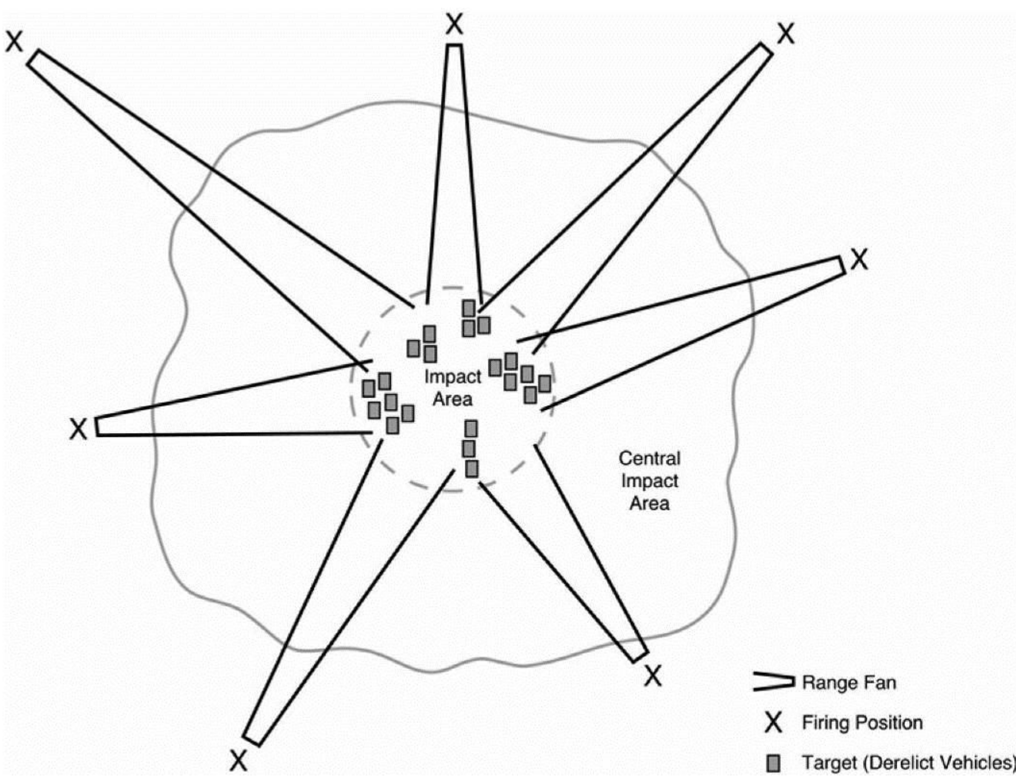


Figure 15. Schematic diagram of an artillery range showing firing points, range safety fan, and impact areas.

to as the safety fan where only a very few rounds impact. Often, this is the largest area of the range. Once the rounds arrive near targets and detonate upon impact, a crater is formed, the size being a function of the type of round, the fuse setting, and the physical properties of the soil. As described earlier, rounds that detonate high order deposit very little energetic residue (the masses of residues deposited has been estimated and is presented in Table 9). For example, three of the six MIS collected in an area 100 by 100 m that had over 600 impact craters present had TNT concentrations less than the detection limit, and the other three ranged from 0.2 to 0.8 mg/kg (Hewitt et al. 2005b). Occasionally a round will impact without detonating, resulting in either a surface or subsurface UXO. On ranges where the soil is rocky or very hard, many of these UXO items can be seen on the surface. In a relatively small number of cases, a round will partially detonate or become breached upon impact, resulting in a low-order detonation (Lewis et al. 2009). A surface UXO can also be partially detonated or cracked open by a nearby high-order detonation. In these cases, none or only a portion of the explosive fill may be consumed, which sometimes leaves a substantial fraction of the explosive fill in or near the ruptured casing (Taylor et al. 2004).

Many artillery ranges have been used for training for decades. The munitions that have been fired into these ranges include ordnance currently in the inventory as well as ordnance used pre- and post-World War 2, during the Korean Conflict and in Vietnam. UXO of a wide array of munitions are present on these ranges and many are still live.

The most common munitions fired into these ranges are artillery rounds and mortars; also used are a variety of rockets, missiles, and Air Force and Navy bombs. Currently the major systems being fired into these ranges include 155- and 105-mm howitzers, 120-mm main tank guns, and 81-, 60-, and 120-mm mortars. Other munitions such as 90-mm recoilless rifle rounds, 4.2-in mortar rounds, 8-in artillery rounds, bombs of various sizes, 40-mm grenades, 106-mm high-explosive plastic (HEP) rounds, 2.75-in LAW rockets, and TOW missiles have also been fired into some of these ranges, as well as some foreign ordnance. These munitions are delivered using single-, double-, and triple-base gun propellants, as well as rocket and missile propellants. The energetic component of single-base gun propellant is composed of NC that contains 2,4-DNT, double-base propellant is composed of NC and NG, and triple-base propellant is composed of NC, NG and NQ. The high explosives used in artillery and mortar warheads are generally either TNT or Composition B, although some older rounds also contained tetryl. Some smoke-generating munitions contain WP. Bombs that have been dropped in some of these ranges contain TNT, Tritonal (TNT and aluminum), or H-6 (RDX, TNT, aluminum), 40-mm grenades contain RDX, and LAW and AT4 rockets contain octol (HMX and TNT).

Artillery and tank range firing points

A number of firing points at various artillery ranges including firing areas for 105- and 155-mm howitzers, various mortars, and 120-mm tank guns have been sampled. The highest concentrations of 2,4-DNT are found at 105-mm firing points. When the concentration of 2,4-DNT in a sample was above 3 mg/kg, 2,6-DNT was sometimes detected at much lower concentrations as well. The compound 2,6-DNT is an impurity in military-grade 2,4-DNT. Soil profile samples indicate most of the propellant residue is present on the soil surface (M.E. Walsh et al. 2004, 2005). Microscopic analysis of the residues indicated that the residues consisted of unburned and partially burned propellant fibers with fiber lengths ranging from 0.4 to 7.5 mm (M.E. Walsh et al. 2007a).

In another example, surface soil was collected at a multi-purpose range complex in front of a fixed firing point for 120-mm tank guns. Both 2,4-DNT and NG were detected at 75 m, the farthest distance sampled from the firing point. Soil samples collected at 155-mm firing points, however, had much lower residue concentrations, often below analytical detection limits.

Artillery ranges away from impact areas and firing points

At several installations, the U.S. Army Environmental Command (AEC) and the U.S. Army Center for Health Promotion and Preventive Medicine (CHPPM) conducted Regional Range Studies to assess the overall environmental impacts of residues from firing activities on artillery ranges (USACHPPM 2001, 2003, 2004, 2005). Extensive studies have also been conducted at MMR (Clausen et al. 2006). Similar studies were conducted by the Defence Research Establishment-Valcartier (Thiboutot et al. 2003, 2004). Because target areas represent only a small fraction of the total area of artillery ranges, many of the areas sampled were quite a distance from any recognizable target. Most of these samples did not contain detectable energetic residues indicating that most of the total area at these ranges is probably uncontaminated.

Artillery and mortar range target/impact areas

Because target areas receive the largest number of detonations, sampling has been preferentially performed around targets at a number of artillery ranges. These targets are generally derelict trucks, tanks, and armored personnel carriers; many have sustained enormous damage after years of target practice. Because of the danger of encountering buried UXO items, and the fact that most detonations scatter residue on the surface, most of the soil samples were collected from the near surface.

Overall, the concentrations of energetic compounds near artillery targets are low and a defined concentration gradient away from the target is not apparent, unlike that found for antitank range target areas. Surface soil samples from some targets can have concentrations in excess of one mg/kg, but the concentrations at most targets are less, sometimes below the detection limits of the analytical methods used. This makes sense based on results of deposition studies showing that very little residue is deposited from rounds that detonate high order, as designed.

Artillery ranges near low-order (partial) detonations and detonation craters

By far the highest concentrations of energetic residues encountered at artillery ranges were associated with rounds that had undergone a low-order detonation (Jenkins et al. 2005c). In most cases, chunks of pure explosive were observed on the soil surface near these items and concentrations of energetic compounds in the surface soil (particles <2 mm) were up to percent levels. Although areas influenced by these low-order detonations were explored in several cases, no generalizations with regard to the sizes of areas contaminated by these events are currently possible; this remains an important research topic. Samples were also collected within impact craters and around their perimeter to determine the residual concentrations of energetic compounds. Overall, areas in and near detonation craters and intact UXO items are not heavily contaminated (Hewitt et al. 2005a). However, destruction of UXO items with C4 demolition explosive can result in a substantial increase of energetic compound concentrations in the near vicinity of the detonations, particularly when they result in a low-order detonation of the item being destroyed.

Bombing ranges

Air Force bombing ranges are very large, generally hundreds of square km in size, but the areas currently used for training with bombs containing high explosives (HE) is much smaller, generally only tens of hectares. Samples have been collected at two live-fire bombing ranges (Ampleman et al. 2003b, 2004, Jenkins et al. 2006b) and several artillery ranges where bombing with HE-containing bombs had occurred (Ch. 2 in Pennington et al. 2002, Jenkins et al. 2004a).

The high explosive present in U.S. and Canadian Air Force bombs is usually Tritonal (TNT, aluminum powder). While no one has sampled residue deposited when a bomb detonates as designed, experimental results for large artillery rounds indicate that large mass HE detonations are very efficient, dispersing only microgram to milligram quantities of energetic residue when they detonate high order. As with other munitions, low-order detonations are undoubtedly the major source of residues from bombs. Communication with range personnel indicates that low-order bomb detonations generally occur several times per year. A low-order bomb can deposit kg quantities of residues as chunks and soil-size particles. Several low-order bombs have been observed during range studies.

Results for soil samples collected at Air Force bombing ranges indicates that high concentrations of TNT (hundreds of mg/kg) are found in the immediate vicinity of low-order bombs that contain Tritonal, but soils concentrations elsewhere are much lower (Fig. 16). The mono amino transformation products of TNT (2AmDNT and 4AmDNT) are also found but at much lower concentrations. RDX has been detected at low concentrations (generally less than 0.1 mg/kg) and its presence may be due to the C4 demolition explosive (91% RDX) used to destroy duds.

Navy and Marine Corps bombs contain H-6 as the main explosive charge. This charge is used because it is composed of RDX, TNT and aluminum, a mixture considered safer for on-ship

Figure 16. Bombing range at Holloman AFB, New Mexico.

storage. Hewitt et al. (2005a) sampled a range where H-6 bombs were dropped. At least one bomb had apparently undergone a low-order detonation. In this area, H-6 chunks were observed and the mean concentrations of RDX, TNT, and HMX in a 100 × 100-m area just down slope of where the largest mass of explosive was located were 9.4, 1.4, and 1.3 mg/kg, respectively.

Open Burn/Open Detonation (OB/OD) Ranges

Military EOD technicians use OB/OD ranges at active DoD training facilities to destroy duds of various munitions that are considered acceptable to move. Sometimes chunks of high explosive or unused propellants are also destroyed at these ranges either by detonation or burning. OB/OD ranges are generally only a few hectares in size and sparsely vegetated near detonation craters. Detonation craters are often used many times before being filled in. At active installations, C4 explosive is placed on the item and detonated using a blasting cap, eliminating any detonation hazards from these items. At some Air Force and Navy demolition ranges, C4 explosive is used to blow a hole in practice bombs to ensure they contain no high explosives before they can be removed from the range for recycling. One such area was sampled and RDX and HMX concentrations in the surface soil from the C4 explosive ranged from approximately one to 30 mg/kg (Jenkins et al. 2006b).

RDX and HMX were generally found in surface soils at the ranges sampled, presumably from the use of C4 demolition explosive (Jenkins et al. 2005c). For example, soil concentrations of RDX and HMX were found to be 11.7 and 2.0 mg/kg, respectively, at a Fort Richardson, AK demolition range (Hewitt et al. 2009). Pieces of C4 are often observed on the surface at these ranges; unlike other ranges, they are present in the subsurface soil as well due to resulting craters and grading of the soils back to a smooth surface. RDX concentrations in the groundwater near the OB/OD range at the MMR were the highest found at the installation (Clausen et al. 2004). RDX has also been observed in groundwater near OB/OD ranges at Camp Bonneville, WA, Camp Grayling, MI, CFB Petawawa, ON, and SUBASE Bangor, WA.

Other energetic compounds such as TNT, NG and 2,4-DNT are also often detected in soils at OB/OD ranges, but generally at lower concentrations than RDX. NG and 2,4-DNT are often present at these ranges.

Small arms ranges

Propellant residues at firing points

A variety of small arms ranges are present at many Army, Navy, Marine Corps, and Air Force installations. These include certification ranges for rifle and pistol as well as ranges for machine gun and vehicle-mounted weapons. At some installations, ranges are also available for use with private sports weapons including pistol, shotgun and rifle. The sizes of small arms ranges vary considerably. On the smaller end are pistol ranges with a bullet catching berm that can be less than 20 m in length; conversely, rifle ranges can be several hundred m in length and as wide as a hundred m. A diagram of a typical small arms range is shown in Figure 17.

In the past, the major environmental concern at these ranges was the accumulation of lead, and more recently tungsten, generally at backstops and berms (see section "Metals and other potential contaminants of concern"). Beginning in 2006, ranges at several installations were sampled to assess the propellant concentrations in soil near firing points for rifle, pistol, and machine gun training locations (Jenkins et al. 2007, 2008).

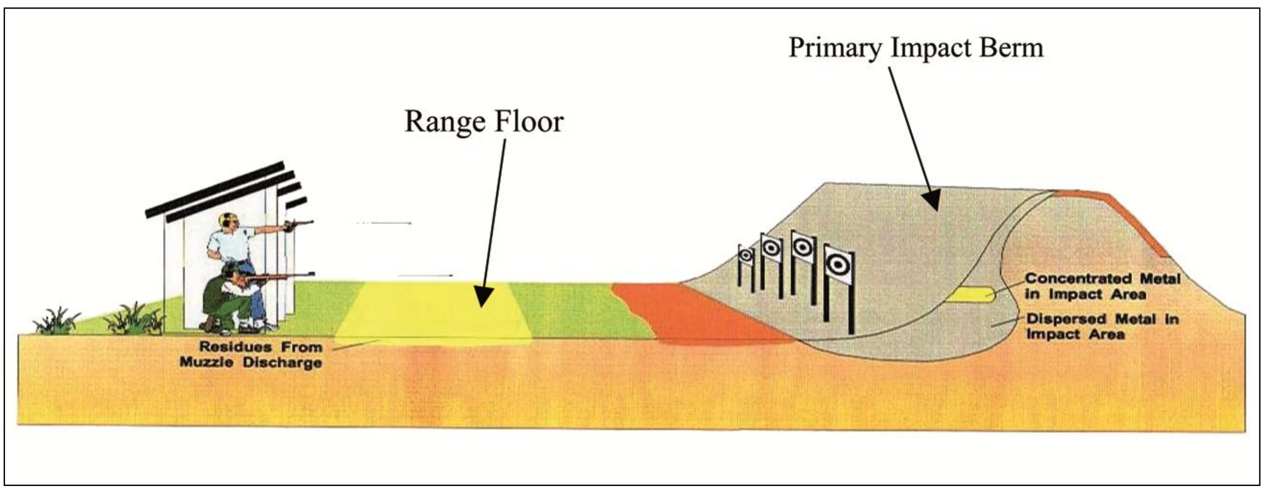


Figure 17. Cross section of a typical static rifle and handgun range (from ITRC 2003).

Table 14 lists the composition of the propellants used for a variety of small arms used by the United States military (M.R. Walsh et al. 2007a). The major component of these propellants is NC, which presents little environmental concern because it is a polymeric material with little or no water solubility and has not been shown to have any environmental toxicity, but may retain ignitable characteristics. Analytical methods for the analysis of NC in soil have been adapted from the method developed by M. E. Walsh (personal communication), but data for NC in soil at ranges is scarce. One study did measure NC in soil along with NG (Chapter 3 in Jenkins et al. 2007). They found that the ratio of NC/NG for soil samples at the various small arms ranges varied substantially from 2.1 to 6.8.

The ratio of NC/NG for soils at firing points should increase over time, as the NG is dissolved from the NC matrix by rainfall and transported or degraded (Martel et al. 2009a). Nitroglycerin is the second most abundant component in military small arms propellant, ranging from 9.7 to 12.5 % for the propellant formulations shown in Table 14. NG is deposited on small arms ranges as a component of NC particles. These particles can have any diameter not exceeding that of the original propellant grain. Generally the residues are smaller because the propellant grain has burned. If burned completely only ash remains, if the grain was barely heated it will look almost identical to an unfired propellant grain (Fig. 18, Taylor et al. Ch. 2 in Jenkins et al. 2008). These particles remain at the surface, and NG slowly leaches from this polymeric matrix into precipitation and soil solution. Estimates of the rate of leaching have been made by controlled drip tests. These tests show rapid initial dissolution of the energetic compounds from all unfired propellants and fired residues tested to date followed by much slower dissolution (Taylor et al. Chapter 2 in Jenkins et al. 2008, Taylor personal communication).

Table 14. Mass of various components in small arms rounds (taken from M.R. Walsh et al. 2007a Appendix Table A2).

		Composition (%)				
Munition	Propellant	NC	NG	DNT	DB*	DP**
9-mm Pistol	WPR289	79.1	12.5			0.9
M-16 Rifle						
5.56 mm (ball)	WC844	66.9	9.9		6.0	1.5
5.56 mm (tracer)	WC844	69.4	10.1		4.8	
M-14 Rifle (7.62 mm)	WC846	80.5	10.0	0.1	5.2	1.1
50 cal Machine gun	WC860	78.9	9.7		8.0	1.1
50 cal Machine gun	WC857	68.5	10.8		5.9	1.2

* DB – Dibutyl phthalate
**DP – Diphenyl amine

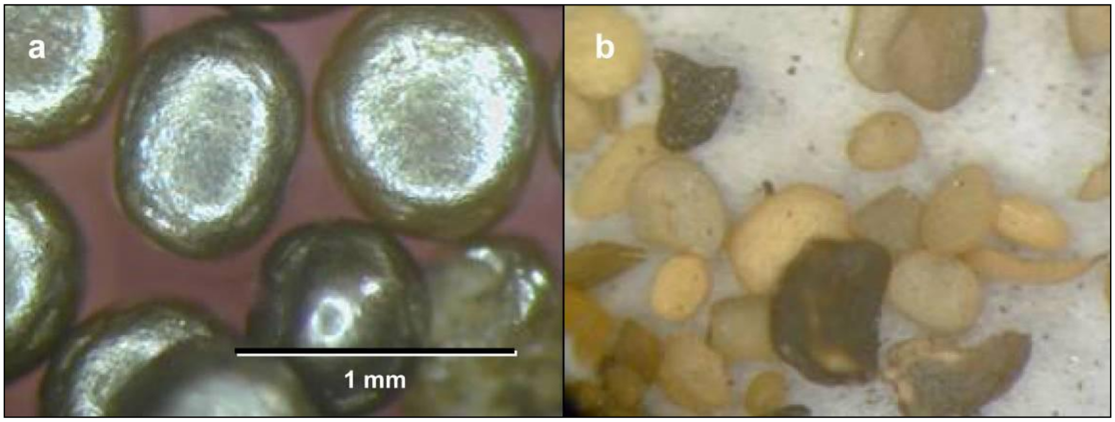


Figure 18 Unfired grains (a) and fired residues (b) from a 0.50 Caliber machine gun photographed at the same scale.

A series of experiments have been conducted at a variety of small arms ranges in the United States and Canada to estimate the distances downrange where residues are deposited. These studies include collection of surface soil in front of the firing positions at a variety of small arms ranges (Table 15), and controlled firing studies where residues were deposited into pans placed on the surface at various distances downrange (Figures 19 to 21).

The concentration of NG in surface soils from 0 to 5 m downrange of the firing line ranged from 8.6 to 413 mg/kg (Table 15). The amount of accumulation is clearly a function of the number of rounds fired at the various ranges. In some cases, 2,4-DNT was also detected in surface soils, but it was generally at two orders of magnitude less than NG. Low concentrations of 2,4-DNT can be present in some small arms propellant.

From these analyses it also appears that most of the propellant residue is deposited within 10 m of the firing line (Fig. 19 to 21). Some minor deposition appears occurred as far as 35 m away from the firing line at the Ft. Richardson Sport Fire range. These distances are somewhat larger than estimated from depositional studies by M.R. Walsh et al. (Chapter 3 in Jenkins et al. 2008). It appears that in general, 99% of the total propellant deposition and accumulation on small arms ranges will be from the firing line to a distance of 20 m downrange, except perhaps for sports fire ranges where some deposition appears to occur beyond 20 m.

Soil depth profile samples were collected at the Ft. Richardson Sport Fire Range and at a 29 Palms rifle range, each at a distance of 2 m ahead of the firing line, and at three ranges at Camp Edwards, MA (Table 16). (Chapter 8 in Jenkins et al. 2008). NG and 2,4-DNT were detected as deep as 6-8 cm in samples collected by digging a pit and carefully sampling from the sidewall at Ft. Richardson. At 29 Palms, NG residues were found as deep as 14 to 18 cm, but 2,4-DNT was

Table 15. Concentration of nitroglycerin in surface soils for various distances downrange at small arms ranges in the United States and Canada.

Location/Range	Type of Use	Samples analyzed	NG Concentration (mg/kg) at Downrange Distance (m)						
			0–5m	5–10	10–15	15–20	20–25	25–30	30–35
Yakima Training Center, WA [1]	Mixed	1	85						
Ft. Lewis, WA[1]	Mixed MG*	5	8.6	2.1	1.2				
	M-16	10	413	252					
CFB/ASU Wainwright, AB [2]	M-9 pistol	3	21						
	M-16	3	13						
CFB-Petawawa, Ontario [2]	M-16	8	15						
29 Palms, CA[2]	MG	3	93	89	15	6.8	2.5		
	M-9 pistol	4	110						
	M-16	10	25	2.9	4.6				
Ft. Richardson, AK [2]	Mixed MG	10	357	336	9.4	4.6	13		
	Mixed Sports	10	113	199	9.1	6.9	12	15	24
Camp Edwards, MA [3]									
Juliet Range	M-9 pistol & M-16	2	3						
Echo Range		2	0.4						
Kilo Range		2	56						

* MG – machine gun

[1] Jenkins et al. 2007; [2] Jenkins et al. 2008; [3] Clausen et al. 2010b

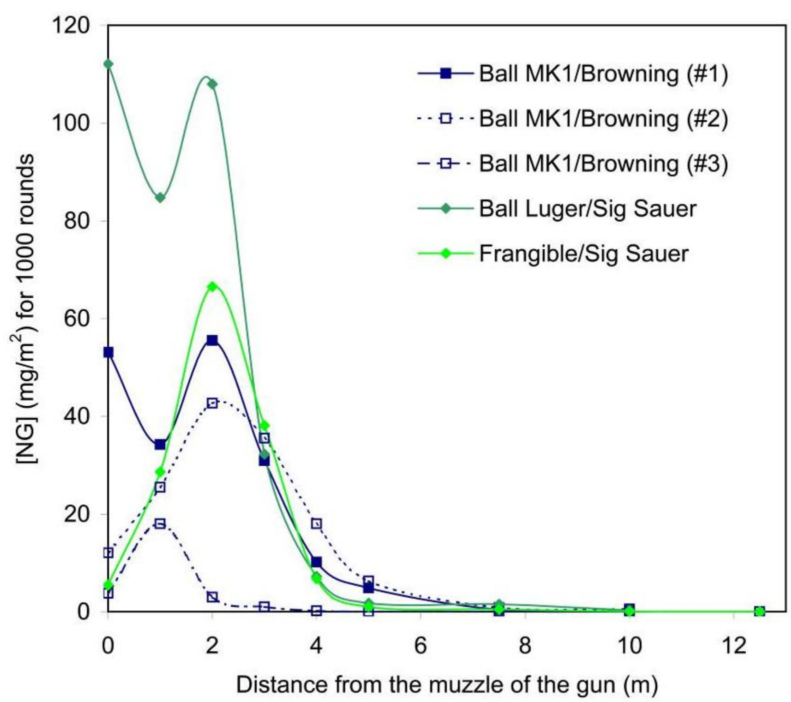


Figure 19. Dispersion of NG on the ground for the 9-mm caliber after 1000 rounds.#1, #2, and #3 are triplicates of Ball MK1/Browning (from Faucher et al. Ch 5 in Jenkins et al. 2008).

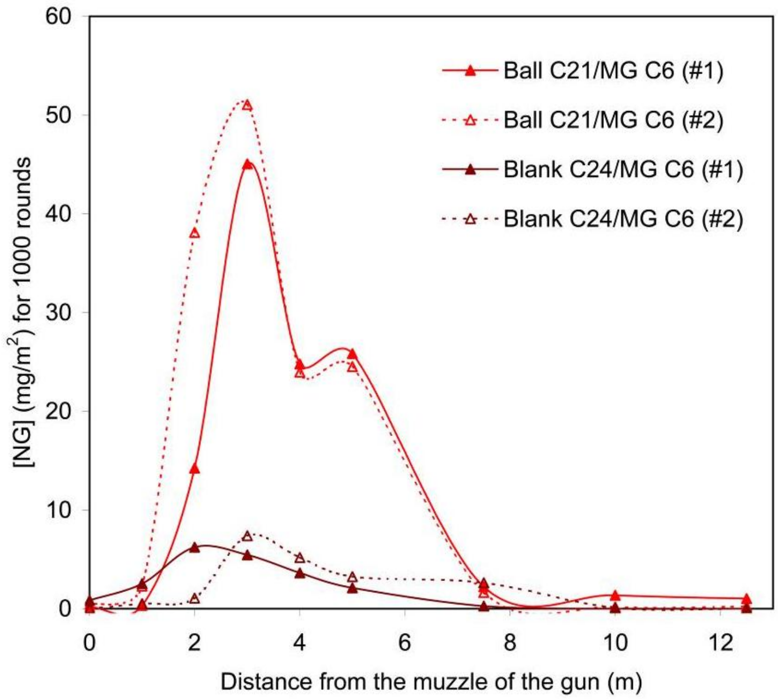


Figure 20. Dispersion of NG on the ground for the 7.62-mm caliber after 1000 rounds. #1 and #2 are duplicates (from Faucher et al. Ch 5 in Jenkins et al. 2008).

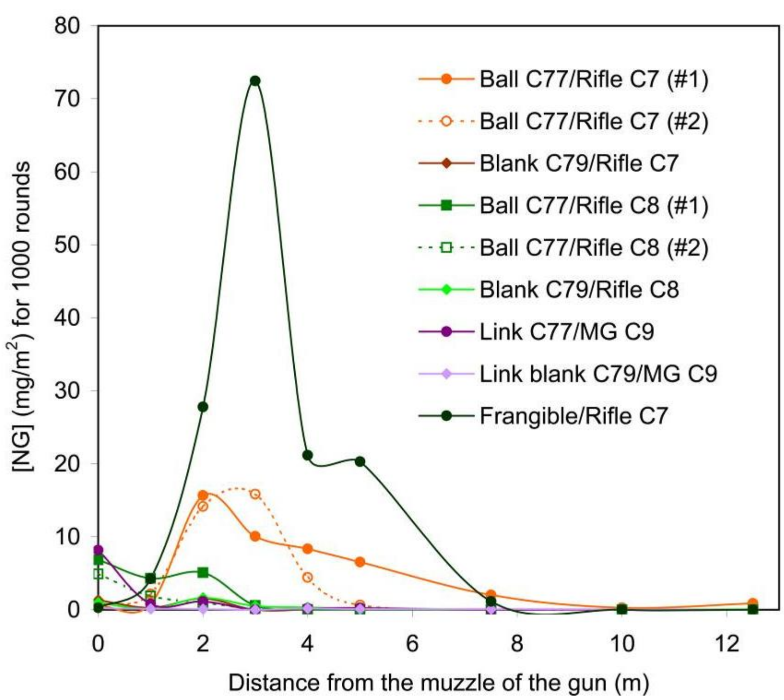


Figure 21. Dispersion of NG on the ground for the 5.56-mm caliber after 1000 rounds. #1 and #2 are duplicates (from Faucher et al. Ch 5 in Jenkins et al. 2008).

Table 16. Concentrations of NG and 2,4-DNT in soil depth profile samples from the Sport Fire Range at Ft. Richardson, AK, a rifle range at 29 Palms, CA (Jenkins et al. 2008) and mixed use ranges (M-9 pistol and M-16 rifle) at Camp Edwards, MA (Clausen et al. 2010a).

	Mean Concentration (mg/kg)									
	Ft. Richardson, AK		29 Palms, CA		Camp Edwards, MA					
	Sport Fire Range		Rifle Range		Juliette Range		Echo Range		Kilo Range	
Depth (cm)	NG	2,4-DNT	NG	2,4-DNT	NG	2,4-DNT	NG	2,4-DNT	NG	2,4-DNT
0–2, 0–8	85.9	1.66	42.3	< 0.04	3.0	0.085	0.4	<0.014	91	1.3
2–4, 2–6	15.7	0.48	9.88	< 0.04						
4–6, 6–10	9.8	0.26	0.64	< 0.04						
6–8, 10–14	6.3	0.16	0.11	< 0.04						
8–10, 14–18	<0.05	<0.04	0.12	< 0.04						
10–15, 18–22	<0.05	<0.04	1.30	< 0.04						
15–20	<0.05	<0.04								
20–25	<0.05	<0.04								
25–30,23–30	<0.05	<0.04			3.4	0.11	0.06	<0.014	1.4	0.05
30–35	<0.05	<0.04								
35–40	<0.05	<0.04								
45–61					0.21	<0.014	< 0.02	<0.014	0.69	<0.014
76–91					0.13	<0.014	< 0.02	<0.014	0.67	<0.014

not detected in any of these samples. These results suggest about 90% of the total NG accumulation and about 88% of the 2,4-DNT accumulation is present in the top 5 cm of the soil profile at Ft. Richardson, and 96% of the NG accumulation is within the top 6 cm at 29 Palms.

Site characterization

Soil sampling studies

Several experiments have been conducted by the Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory (ERDC-CRREL) of the U. S. Army Corps of Engineers for the purposes of (1) evaluating alternative strategies for collection of representative samples to characterize exposure areas at training range firing points and impact areas and (2) assessing laboratory sample processing and analysis protocols for accurate and precise determination of residue concentrations in these soil samples.

Site characterization studies for environmental assessments have often used what is commonly referred to as the grid-node sampling approach. Using this strategy, the area of interest is divided into a number of individual sampling units, the size of each being a function of the total area to be assessed and the future land use envisioned. Within each sampling unit, one (or sometimes several) discrete sample(s) is collected and shipped to an offsite contractor laboratory where samples are processed and analyzed. The results of these analyses are assumed to be representative of concentrations within the sampling unit and the concentrations of the individual samples are generally assumed to be normally distributed. The assumption that these discrete samples are "representative" of analyte concentrations within the sampling unit is generally not tested, although the concentrations determined for discrete samples collected from within the same unit often do not agree. The results from these discrete samples are then used to calculate the mean concentration for that sampling unit.

Results from discrete sampling at ranges

Because earlier research had indicated that explosive concentrations in discrete samples can vary substantially even over short distances (Jenkins et al. 1997a,b; 1999), and because energetic residues are deposited at training ranges as discrete particles (Taylor et al. 2004, 2006), there was concern about using discrete samples to represent the average concentrations in soil at firing points and impact areas. To test just how diverse individual discrete samples might be from within these areas, experiments were conducted at firing points and impact areas at several different military training ranges. In most cases, a 10 × 10-m sampling unit was established and subdivided into one hundred 1 × 1-m cells. A discrete sample was collected from each cell and analyzed for energetic compounds according to established protocols (SW846 Methods 8330 or 8330B).

The major analyte detected in seven different sampling units at six different installations varied from 2,4-DNT and NG at firing point areas to RDX, TNT and HMX at impact areas (Table 17). Maximum to minimum concentration ratios varied from over two orders of magnitude to almost five orders of magnitude for these sets of 100 discrete samples, indicating individual or small numbers of discrete samples cannot yield reliable estimates of mean concentrations within

Table 17. Variability of soil concentrations among 100 discrete samples collected within 10-m x 10-m sampling units at various training range impact areas.

Installation	Area*	Range type	Analyte	Concentration (mg/kg)				
				Max	Min	Median	Mean	Std dev.
Donnelly Training Area (AK)[1]	FP	Artillery	2,4-DNT	6.38	0.0007	0.65	1.06	1.17
CFB-Valcartier (QC)[2]	FP	Antitank rocket	NG	2.94	0.02	0.281	0.451	0.494
CFB-Valcartier (QC)[2]	IA	Antitank rocket	HMX	1150	5.8	197	292	290
Holloman AFB (NM)[3]	IA	Bombing	TNT	778	0.15	6.36	31.8	87.0
Ft. Polk (LA)[4]	IA	Mortar	RDX	2390	0.037	1.7	71.5	315
Cold Lake (AB)[5]	IA	Bombing	TNT	289	0.38	6.57	16.2	32.3
Ft. Richardson (AK)[6]	IA	Artillery	RDX	172	<0.04	<0.04	5.46	24.8
Ft. Richardson (AK)[7]	IA	Mortar	RDX	4450	<0.04	<0.04	—**	—

* Firing point (FP) or Impact Area (IA). [1] M.E. Walsh et al. 2004, [2] Jenkins et al, 2004b, [3] Jenkins et al. 2006b, [4] Jenkins et al, 2004a, [5] Ampleman et al. 2004, [6] M.E. Walsh et al. 2007b. [7] Hewitt et al. 2009 (Note: results from 200 discretes).
** — Not computed

samplings units as small as 10 × 10 m. In fact, the maximum and minimum concentrations among nine discrete samples collected within a single 1×1-m cell varied by two orders of magnitude, demonstrating the magnitude of short-range heterogeneity in these areas (Jenkins et al. 2006b). This extreme heterogeneity is due to the presence of particles of energetic residues. Median values for the hundred discrete samples within each data set were always less than the mean, indicating most discrete samples underestimated the mean. The standard deviations for these sets of 100 discrete samples were always equal to or greater than the means, indicating that in no case were the concentration estimates from discrete samples normally distributed. In general, estimating a mean based on just a few discrete samples will result in a mean value that is biased low.

Results from MULTI-INCREMENT samples at ranges

Another approach investigated to estimate mean concentrations within a sampling unit was use of *MULTI-INCREMENT*®samples (MIS®). In this document, the term sampling unit will refer to the area that the sample is intended to represent. This area has sometimes been referred to as the decision unit or the sampling grid. Here, instead of collecting and analyzing single point samples and integrating the results for an area or assuming a single point is representative of the entire area, samples are built by combining a number of increments of soil from within the sampling unit to obtain a ~ 1-kg sample. The increments can be collected in a totally random fashion or more systematically. In the systematic-random pattern, a random starting point is selected and increments are gathered on an even spacing as the sampler walks back and forth from one corner of the sampling unit to the opposite corner (Fig. 22).

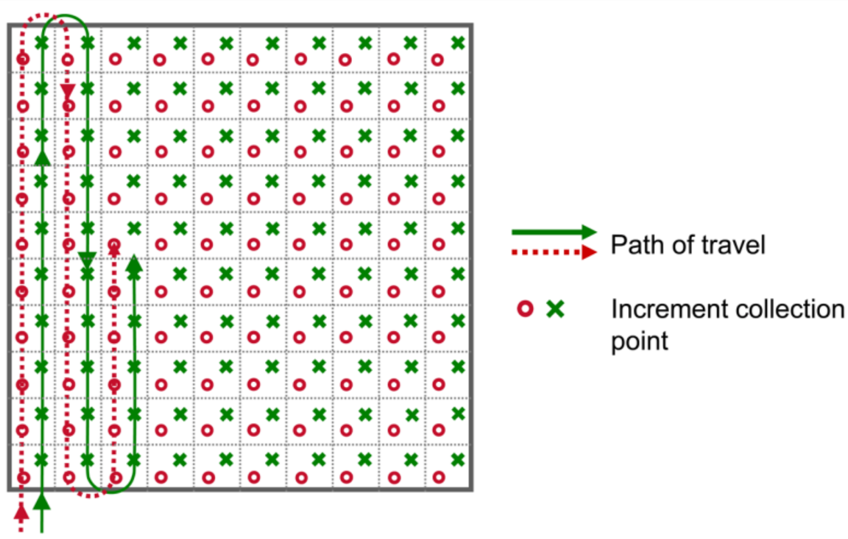


Figure 22. Illustration of *MULTI INCREMENT* sampling using a systematic-random sampling design for collecting two separate 100-increment samples.

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In several comparative sampling studies, the variability among replicate MIS was much lower than for discrete samples taken within the same sampling units (Table 18). For example, 2,4-DNT concentrations in discrete samples collected within a 10 × 10-m firing point sampling unit at Donnelly Training Area ranged over almost four orders of magnitude, whereas concentrations among the ten replicate MIS from this sampling unit varied by less than a factor of three. Similarly, the range in RDX concentrations for discrete samples from a 10 × 10-m sampling unit at a Ft. Polk impact area varied by nearly five orders of magnitude; the range for MIS was reduced to less than two orders of magnitude. The study at Ft. Polk employed a totally random collection scheme for the MIS; subsequent research indicated that more reliable results were obtained using a systematic-random design where increments are collected across the entire sampling unit and no areas are ignored or over-sampled (Fig. 22).

Sampling units up to 100 × 100 m have been sampled using the MIS approach. The number of increments in each MIS varied from 30 to 100, depending on the grid size being characterized and the amount of chunks of pure energetic compound observed on the surface (Jenkins et al. 2005b). Triplicate samples varied from 3.9 to 9.4 mg/kg for RDX for soil samples from an impact area at 29 Palms, CA (Hewitt et al. 2005a) and from 3.96 to 4.26 mg/kg for HMX for samples from a thermal treatment area at Hill AFB (Nieman 2007). MIS provided much more reproducible estimates of mean concentrations within sampling units at firing point and impact areas than one or a few discrete samples. MIS should be collected using a systematic-random pattern rather than a totally random pattern that sometimes over- or under-represents various areas of the sampling unit (Fig. 22). In addition, when sufficient replicates were obtained, replicate MIS were often found to be normally distributed whereas the data distribution of discrete samples was always non-normal. This is a direct result of the central limit theorem of statistics that can be

Table 18. Variability of soil concentrations among replicate multi-increment samples (MIS) collected within sampling units at various ranges.

Installation	Area*	Range type	Increments/ Sample	Replicate Samples	Sampling unit size	Analyte	Concentration (mg/kg)				
							Max	Min	Mean	Std dev.	Median
Donnelly Training Area (AK)[1]	FP	Artillery	30	10	10 x 10 m	2,4-DNT	1.35	0.60	0.94	0.24	0.92
Holloman AFB (NM)[2]	IA	Bombing	100	3	10 x 10 m	TNT	17.2	12.5	14.4	2.45	13.5
Ft. Polk (LA)[3]	IA	Mortar	25	10	10 x 10 m	RDX	290	4.6	54	86	25
29 Palms (CA)[4]	IA	Artillery/ Bombing	100	6	100 m x 100 m	RDX	9.4	3.9	5.6	2.1	4.8
Hill AFB (UT)[5]	TTA	Thermal treatment	100	3	100 m x 100 m	HMX	4.26	3.96	4.13	0.15	4.16

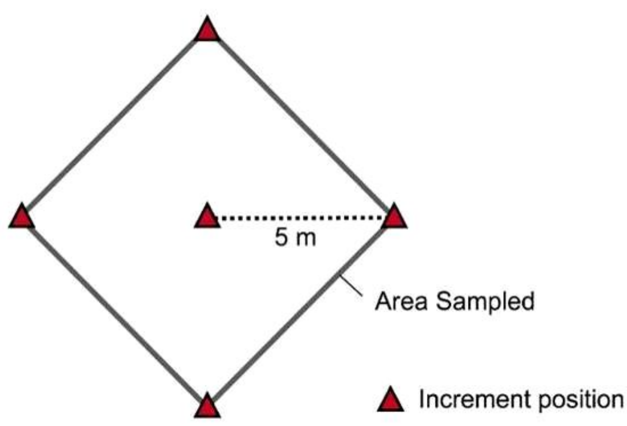
* Firing point (FP), Impact Area (IA), or Thermal Treatment Area (TTA). [1] M.E. Walsh et al. 2004, [2] Jenkins et al. 2006b, [3] Jenkins et al, 2004a, [4] Hewitt et al. 2005a, [5] Nieman 2007

rewritten for MIS: as the number of individual increments in each MIS gets "large enough," the distribution of replicate MIS can be approximated by a normal distribution, regardless of the shape of the distribution of individual increments. Thus, the more increments collected, the more representative the sample will be. For areas where solid pieces of the energetic compound are present on the surface, replicate MIS samples will often not be normally distributed.

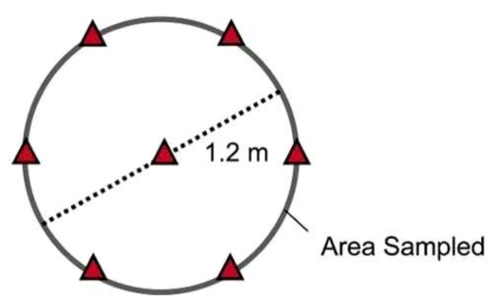
Comparison of discrete, wheel, box, and MIS approaches at impact areas and firing points

Two other approaches have been used to estimate mean explosive concentrations for sampling units at training ranges. The first is a "box" sampling design in which a five-increment sample is obtained from a 7 × 7-m sampling unit with increments collected from the center point and the four corners as shown in Figure 23a (USACHPPM 2001, 2003, 2004, 2005). The second, shown in Figure 23b, uses a "wheel" sampling design with a seven-increment sample collected with six increments from the periphery of a 1.2-m diameter circle and the seventh from the center. These two approaches were compared with the collection of discrete samples and 100-increment MIS samples in a study conducted by Roote (2010). Four replicate samples were collected using each design and the results were compared. This was done at a bombing range impact area where TNT was the major contaminant, and at an antitank firing point where NG was the contaminant of interest (Tables 19 and 20).

In both cases, the relative standard deviation (RSD) was much lower for MIS than for the discrete, box, or wheel sampling approaches and thus provides a much more reliable estimate of the mean concentration for the sampling unit.



a. Five-increment 50-m^2 box.



b. Seven-increment 1.2-m diameter wheel.

Figure 23. Two conventional sampling designs evaluated.

Table 19. Concentration of TNT (mg/kg) in soil samples from Holloman AFB, NM bombing range impact area, comparison of different sample collection strategies (from Roote 2010).

Sample Type	TNT Concentration (mg/kg)				Mean	Std Dev	% RSD
	*Rep. 1**	*Rep. 2*	*Rep. 3*	*Rep. 4*			
Discrete	1900	11	37	200	537	913	170
Box	1100	160	6400	3700	2840	2810	99
Wheel	0.6	21000	42	90	5280	10,500	198
MIS**	1500	2100	1000	1700	1580	457	29

* Rep. – Replicate

** 100 increments for each MIS

Table 20. Concentration of NG (mg/kg) in soil samples from antitank rocket firing range at Ft. Lewis, Washington, comparison of different sample collection strategies (from Roote 2010).

Sample Type	NG Concentration (mg/kg)				Mean	Std Dev	% RSD
	*Rep.1**	*Rep.2*	*Rep.3*	*Rep.4*			
Discrete	2300	1900	1550	6360	3050	2230	73
Box	5320	1520	4200	5120	4040	1750	43
Wheel	2470	3490	1800	2400	2540	701	28
MIS	1630	1890	1990	1950	1870	162	9

* Rep. – Replicate

Sampling depth

As discussed above, accumulation of energetic residues at ranges occurs as particles on the soil surface of either pure or mixtures of explosive compounds and as fibers and particles of propellants and rocket fuels. Locations where high concentrations of these energetic particles are typically found include: firing points for certain types of munitions, sites where munitions have low-ordered (undergone a partial detonation) or ruptured (breached upon impact or by proximate detonations), sites where disposal activities occur frequently, and sometimes where UXO is blown-in-place on impact ranges. Figure 24 shows two examples of unconsumed particles: one photograph shows TNT particles collected after the blow-in-place of a 155-mm howitzer round with a block of C4; the other shows fibers that accumulated on snow in front of a gun where the M1 propellant was used to accelerate 105-mm howitzer projectiles downrange.

The chemicals in these energetic particles have low vapor pressures. Therefore, the principal mechanisms that determine the fate of these chemicals include dissolution, transformation, and for some, chemical mineralization. Figure 25 shows concentration profiles of energetic residues obtained directly beneath chunks (> 2 cm) of explosives found on the surface. Concentrations in the surface soil immediately beneath the chunks were a consequence of small (< 1 mm) particles washed off or abraded from the surface. With increasing depth, the concentration results from the migration of dissolved energetic analytes. The inherently lower concentrations of energetic chemicals in the subsurface result from a combination of limited solubility, limited volumetric

Figure 24. Examples of energetic material particles: TNT particles (<1 mm, fraction) from a blow-in-place detonation (left), 105-mm howitzer propellant fibers from a collection tray 3 m from muzzle (right, 1-mm scale).

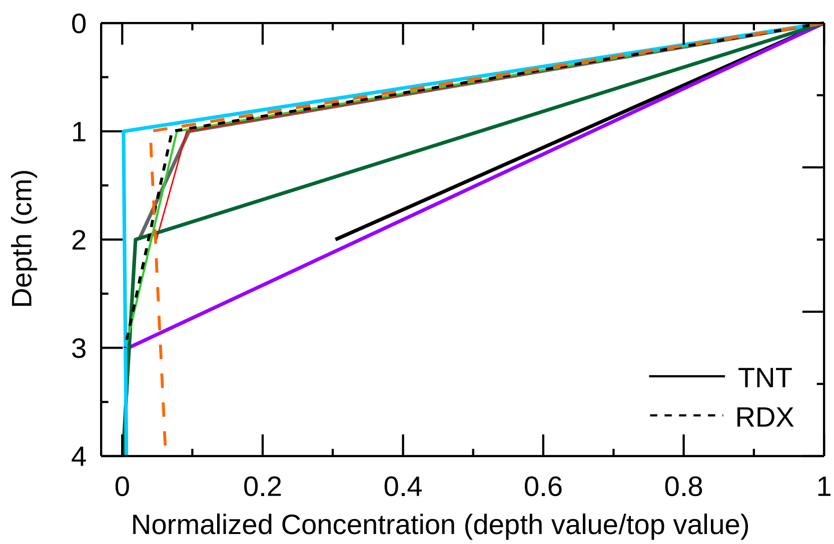


Figure 25. Normalized profile showing decreasing concentration in energetic compounds with depth directly beneath seven TNT chunks (> 2 cm) found on the surface at Fort Bliss and two chunks of Composition H-6 at 29 Palms. Equivalent samples are shown in the same color.

soil moisture content, and low soil/water partition coefficients. A large decrease in energetic residue concentrations with profile depth is also characteristic of firing point locations. Therefore,with the exception of ranges where the surface is physically moved and particles become buried, the highest concentrations are present at the ground surface on active ranges (Jenkins et al. 2006a, Hewitt et al. 2005a). Generally, most of the energetic residues are within the top 10 cm; in many cases, the vast majority is in the top 2.5 cm. Once the energetic residue particles have been completely dissolved, it is unlikely their presence will remain detectable in surface soils for more than a couple years. That is, once energetic residues no longer are present in the solid form, they degrade or migrate away from the original source area. In arid regions, however, dissolution can take many decades.

Vegetation

Because most energetic particles are near the ground surface, the surface vegetation (short grasses and mosses) should not be removed prior to sampling on active ranges. Figure 26 shows examples of vegetation at a firing point and surrounding a crater where an 81-mm mortar had low-ordered on an artillery impact range. If vegetation is removed or patches of vegetation are avoided, energetic residues trapped within this portion of the surface matrix will not be included in the sample and the analyzed amount of energetic residue is likely to be underestimated. Use of specially designed (Fig. 27, M.R. Walsh 2004) or commercially available coring tools at vegetated sites aids

Figure 26. Examples of surface vegetation at a firing point (inset) and in and around a crater of an 81-mm mortar low-order detonation crater on an artillery impact range.

Figure 27. Coring tool designed specifically for collecting cohesive multi-increment soil samples.

in the collection of surface samples with minimal surface disturbance and human effort. Most importantly, use of coring tools helps avoid biased sampling, i.e., sampling only the exposed soil surfaces. In addition, this type of sampling tool enhances surface area, depth, and increment volume precision. With the exception of very thick vegetative mats, vegetation from the surface interface included with a soil sample typically makes up less than a percent of the total dry sample weight.

Sampling Design

<u>Sampling Theory</u>

Representative sampling should be a major project objective (USEPA 2002, 2003; D.M. Crumbling personal communication). To do so, the sampling strategy must address the compositional and distribution heterogeneity of the constituents of concern (Pitard 1993). Compositional heterogeneity is due to the fact that not all soil-sized particles within the population have the same concentration of target analytes. This heterogeneity is at a maximum when a portion of the target analytes is present as discrete particles. Error due to compositional heterogeneity is called the fundamental error and is inversely related to the sample mass. A more thorough discussion of fundamental error is provided in Appendix B. Distributional heterogeneity is due to contaminant particles being scattered across the site unevenly, sometimes with a systematic component as well as a short-range random component. Error associated with distributional heterogeneity is inversely related to the number of individual increments used to build the sample. This type of error is at a maximum when a single discrete sample is used to estimate the mean for a larger sampling unit (sampling unit – population, area of concern, ecological habitat, etc). To reduce the influence of distributional heterogeneity in the estimate of the mean concentration for a sampling unit, the collection of 30 or more evenly spaced increments to form an individual soil sample has been recommended (Jenkins et al. 2004a,b, 2005c, 2006a; M.E. Walsh et al. 2005; Hewitt et al. 2005a). The objective of this MIS strategy and systematic random design is to obtain a single sample that contains all constituents, including energetic residue particles of every composition as well as non-energetic particles, in exactly the same proportion as they are present in the entire sampling unit.

In the past, the estimate of mean concentration for a sampling unit has often been derived from the collection and analysis of one or several discrete samples. Studies comparing discrete and MIS sampling strategies for the characterization of military training activities, discussed earlier, have shown that the distribution of data obtained from discrete samples is always non-Gaussian and positively skewed, whereas that from a multi-increment data set is often normally distributed (Jenkins et al. 2004a,b, 2005c, 2006a; M.E. Walsh et al. 2005), a result consistent with the central limit theorem of statistics. Moreover, a single discrete sample or small set of discrete samples almost always results in a lower estimate of the mean concentration than the multi-increment sampling strategy. As the number of discrete samples collected approaches the number of increments in a single multi-increment sample, the differences between the estimates of mean concentrations resulting from these two strategies converge. However, each replicate MIS is an independent estimate of the mean and collection of multiple replicate MIS provides an estimate of the error in the mean concentration estimate, something that is never done with discrete sampling strategies.

Uncertainty

The total measurement error includes contributions from sample collection, sample processing, and analytical determination. The best way to estimate the total measurement error, or uncertainty of the mean concentration of contaminants in a sampling unit, is to collect and analyze replicate field samples. It must be emphasized that these are not field splits, but rather independently collected samples from within the sampling unit. If it is important to compute a 95% upper confidence limit (UCL) for the mean concentration within a sampling unit, then this can be done by collecting triplicate MIS. The standard deviation computed from the triplicate results can be used for the 95% UCL computation. A percentage of the total multi-increment samples collected for a given characterization activity should be done in triplicate, the actual percentage being determined on a site-specific basis depending on the data quality objectives.

The ability to achieve low sampling error depends on the sampling strategy and the military training activity under investigation. In general, the more repetitious a given activity, e.g., projectiles fired or detonations occurring in the same general location, the more likely the distribution of energetic residues will become more pronounced (heavier accumulation) and less heterogeneously distributed. As a consequence, sampling uncertainty is likely to be lower at sites such as a fixed firing position, near a direct line-of-sight target, and at a disposal range than at sites around a target or former target on an indirect fire impact range. Studies at firing points and within impact ranges have supported this anticipated trend and have shown that analyte variability is much greater for a large set of discrete samples (n=30) than for a small set (n=3) of replicate 30-increment samples (Jenkins et al. 2004a,b, 2005c, 2006a; M.E. Walsh et al. 2005). This is a common characteristic of analytes that are heterogeneously distributed as particles. For many environmental programs, this source of uncertainty (i.e., determining if the sampling strategy results in representative samples as inferred from the ability to reproduce the sampling results) has often been ignored. This is particularly alarming in light of studies showing sampling error to be the largest portion of the total characterization uncertainty for energetic residues on military training sites (Jenkins et al. 1997a,b, 1999). Therefore, both scientific (data quality) and economic advantages can be realized through the processing and analysis of multi-increment samples (Hewitt et al. 2009).

Sampling unit size

The sampling unit size needs to vary depending on the manner in which the deposition has occurred. For example, at an artillery range firing point the residue is dispersed over a fairly large (e.g. 10,000 m^2) area from a single training exercise. Near a low order detonation, the size of the impacted area can be rather small (e.g. 25 m^2). In some cases, the sampling unit can cover the entire area where it is thought that the most energetic residues are present. Situations where a single sampling unit might be utilized include firing points, blow-in-place detonations, direct line-of-fire impact areas (e.g. antitank ranges), and observed individual low order detonations (Hewitt et al. 2005b; M.R. Walsh et al. 2005a, b, c, 2006). Multiple sampling units may be needed at indirect fire impact areas. However, research is continuing on the appropriate sizes of sampling units for various activities.

Factors to consider when choosing sampling unit size include the total size of the area influenced by the activity and what constitutes a manageable sample for field and laboratory operations without compromising data quality. These parameters coupled with range use records, range function and design, surface conditions, and the data quality objectives should all be considered when deciding where to sample and the size of the sampling unit. In some cases the area impacted by an activity is so large that it must be divided into multiple sampling units. A practical guide for the setting up sampling units and collection of MIS is provided in Appendix C.

Visual observation of low order detonations and field screening

Chunk residues (pieces of energetic materials > 2 mm) often are present within and around ruptured (low-ordered or breached) munitions and in areas where OB/OD of off-specification, obsolete, or excess energetic materials has been performed. Special precautions should be taken when sampling around low-order detonations and ruptured munitions, both of which often fall under the classification of munition and explosives of concern (MEC). First, the size of the sampling unit should at least encompass the area with visible residues. Delineating this area covered with visible pieces of energetic residues will result in high energetic residue soil concentrations, a possible source zone for surface and ground water contamination. Field analytical screening techniques should be used to identify chunks of energetic residues. Methods approved by the EPA include colorimetric SW-846 Methods 8510 and 8515. Immunoassay Methods 4050 and 4051 (US EPA 2000; US EPA 1996a, b, c) are no longer commercially available. Other screening techniques, such as use of the Expray™ kit, can identify explosives (Plexus Scientific, Silver Spring, MD; Bjella 2005). Once identified, chunks of energetic materials should be gathered, weighed (if not adhering to a munitions casing), and removed by EOD personnel or UXO technicians prior to sampling. Additional information regarding residue identification and the safety concerns are presented in Method 8330B (US EPA 2006).

Systematic random sampling

A systematic-random sampling design is recommended when collecting individual increments to build each MIS (Hewitt et al. 2005b, 2007b). This sampling design is analogous to systematic grid sampling (US EPA 2002), in which an initial position is chosen and the remaining sampling locations are laid out in a regular pattern (Cressie 1993). In the systematic random design, the sampler begins at a randomly chosen point on the edge of the area to be characterized and collects an increment of surface soil after a predetermined number of steps, while walking back and forth in a systemic manner across the area of interest. Figures 22 and 28 show examples of the path a sampler would take using this sampling design for square and circular areas. This provides an unbiased spatial coverage and ensures that the distance between any two increments is minimized. The proper number of increments needed in order to obtain a representative (reproducible) sample is a function of the distributional heterogeneity. The total mass of each increment and total mass of the sample is a function of the compositional heterogeneity. The number of increments and size of the sampling units cited for the range-sampling activities described below have often produced replicate samples with similar analyte concentrations. Generally, samples must contain a minimum of 30 increments to produce replicates that are normally distributed (Jenkins et al. 2004a). The assumption is that the distribution of energetic residues is similar between military facilities with ranges designed for the same activity is the basis for the recommended sizes of sampling units and number of increments. Because increments are being combined to create a single sample, cleaning the sampling tool between collecting increments of a given sample is unnecessary. A clean sampling tool is necessary for each new sampling unit.

Sample Processing

Multi-increment samples collected with the sampling designs described above and in the following sections are typically 1 kg or greater. Laboratory analysis is conducted on a small portion of the sample, referred to as a subsample. Method 8330B Appendix A (US EPA 2006) provides guidance on how to process soil samples so they can be representatively subsampled in preparation for analysis. Several studies cited in the revised method have shown that in order to determine representative analyte concentrations in soils containing energetic residues, they must either be

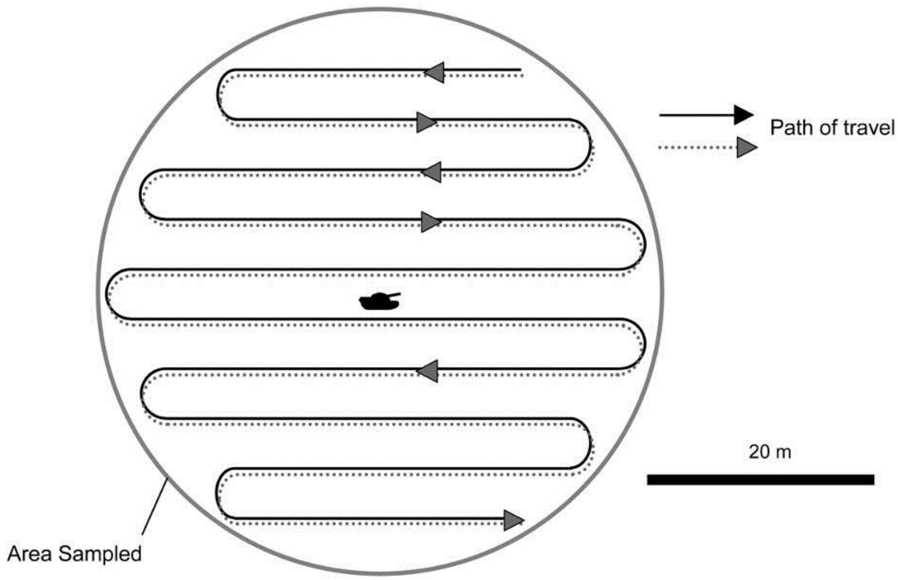


Figure 28. Systematic-random multi-increment sampling design surrounding a tank target at the impact area of an anti-tank range.

ground before subsampling or the entire sample must be extracted. Following the guidance in Method 8330B, the results for laboratory replicate subsamples have been shown to be both reproducible and experimentally accurate (method established accuracy), since in a few cases, the remaining sample was extracted in its entirety and analyzed to obtain an estimate of the true sample mean concentration subject only to analytical uncertainty, and thus eliminating all error due to sample processing and subsampling.

Multi-increment Sampling

Multi-increment sampling using a systematic-random sampling design is recommended for estimating mean concentrations of energetic compounds at all the military training ranges addressed in this document. In addition, collecting triplicate multi-increment samples is strongly recommended for at least one sampling unit on each type of training range under investigation. To aid in the collection of multi-increment samples with a targeted weight of approximately 1 kg, special sampling tools may need to be acquired so as to obtain the appropriate incremental mass relative to the recommended number of increments and sampling depth (Appendix C). The coring tools, shown in Figure 27, are made with 2- and 3-cm inner diameters to help meet these needs. Oakfield corers or similar push tube devices are soil sampling tools available in several different core barrel widths and lengths. These soil-coring tools are easy to operate in cohesive soils. However, they are not practical for some cobbled and non-cohesive soils. Metal or hardened plastic scoops and trowels are more suited for use in cobble-rich and non-cohesive (sandy) soils. Both of these soil-sampling tools are available from equipment vendors such as AMS (http://www.ams-samplers.com/), Forestry Suppliers, Inc. (http://www.forestry-suppliers.com/), Enviro-

Tech (http://www.envirotechonline.com/), and Ben Meadows Company (http://www.benmeadows.com/).

It also should be noted that the guidance provided herein also applies to the surfaces of other ranges not specifically addressed in this document that are operationally similar. For example, on direct line-of-sight ranges, the areas anticipated to have the highest accumulation of munitions constituents would be at the firing point and around targets.

Recommended sampling protocols

Hand grenade ranges

At hand grenade ranges, the sampling area should be an area between 5 and 40 m in front of the throwing bay and the width of the impact zone. For grenade courts that are not separated by barriers, the entire impact range can be characterized as a single sampling unit. When walls or other features separate the impact zone into several distinct areas, at least one MIS should be taken for each impact zone.

Individual increments for multi-increment samples should be collected from the soil surface to a depth of 10 cm. If the surface area to be characterized is less than 100 m^2, the sample collected should include 30 or more increments. For larger areas, samples consisting of 50 or 100 increments are recommended. In both cases, the sample collection pattern should be as shown in Figure 22.

Profile sampling is recommended for those ranges where the surface has been disturbed and, as a consequence, particles may be present in the subsurface. Within the area with the highest crater density, at least five depth profiles should be collected in 10-cm intervals down to a depth of at least 30 cm. Sample increments from the same 10-cm depth interval (0–10 cm, 10–20 cm, and 20–30 cm) should be combined to produce a single five-increment sample (Fig. 29). Because of the limited number of increments, this sampling strategy is best suited for determining the depth to which residues have been mixed into the soil profile and not to estimate the average concentration for a subsurface layer over a large horizontal cross-sectional area. To achieve this second objective, 30 to100 increments should be collected. For depths below 30 cm, a surface geophysical survey may not be sensitive enough to detect grenades; therefore, down-hole clearance should be performed.

If a ruptured grenade with energetic residues on its interior surfaces or a grenade surrounded by chunk residues is encountered, an area that encompasses the visibly affected surface should be sampled as a separate sampling unit. Prior to sampling, all visible pieces of energetic residues (i.e., energetic residues present as MECs) should be removed. A 30-increment sample should be collected from the sampling unit.

Anti-tank rocket ranges

<u>Targets</u>

Studies of anti-tank rocket range impact areas indicate that most the residues are within a 25-m radius of targets (Jenkins et al. 1997b, 2004b; Thiboutot et al. 1998). To estimate the mass of residues on these ranges, multi-increment samples collected within a 25-m radius around each target is recommended (Fig. 28). Because the area represented by each sample will be about

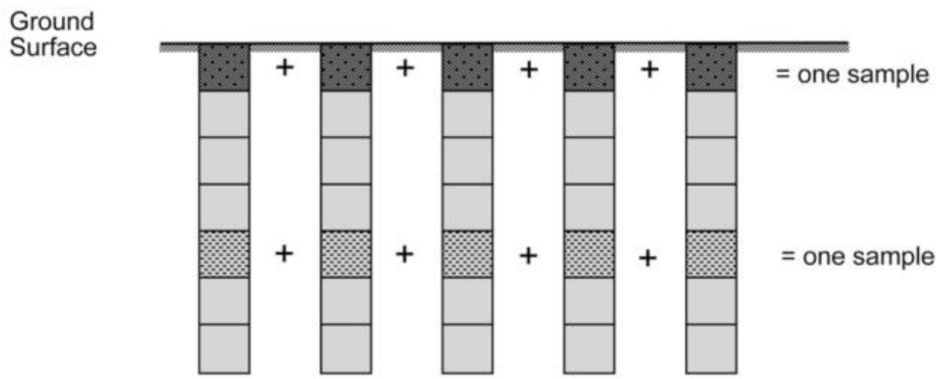


Figure 29. Schematic of procedure to collect multiple-increment profile samples where transport and deposition of energetic materials is suspected.

2000 m^2, 100 increments of the top 5 cm are recommended. In general, more increments are required to adequately characterize larger sampling units; otherwise the distance between increments may be inadequate to capture residues from individual events.

If a more detailed characterization is required, a segmented halo design is recommended (Jenkins et al. 2004b, Pennington et al. 2004). In this design, as shown in Figure 30, concentric rings are established at distances of 5, 15 and 25 m from the target, the rings are segmented, and multi-increment samples are collected within each segment. Because the surface area within a segment is relatively small, each sample should be built from 30 increments.

Profile sampling at anti-tank ranges can be conducted to look for subsurface migration of dissolved energetic residues. Unlike hand grenade ranges, particles remain on the soil surface at anti-tank impact ranges and only the dissolved compounds will be transported downward. Any sampling for this purpose should be done immediately in front of the heaviest impacted target, where surface concentrations will likely be very high. Since the area in front of the target is relatively small, this can be performed as a single sampling unit encompassing at least five profiles with at least five sampling intervals within the top 60 cm (Fig. 29).

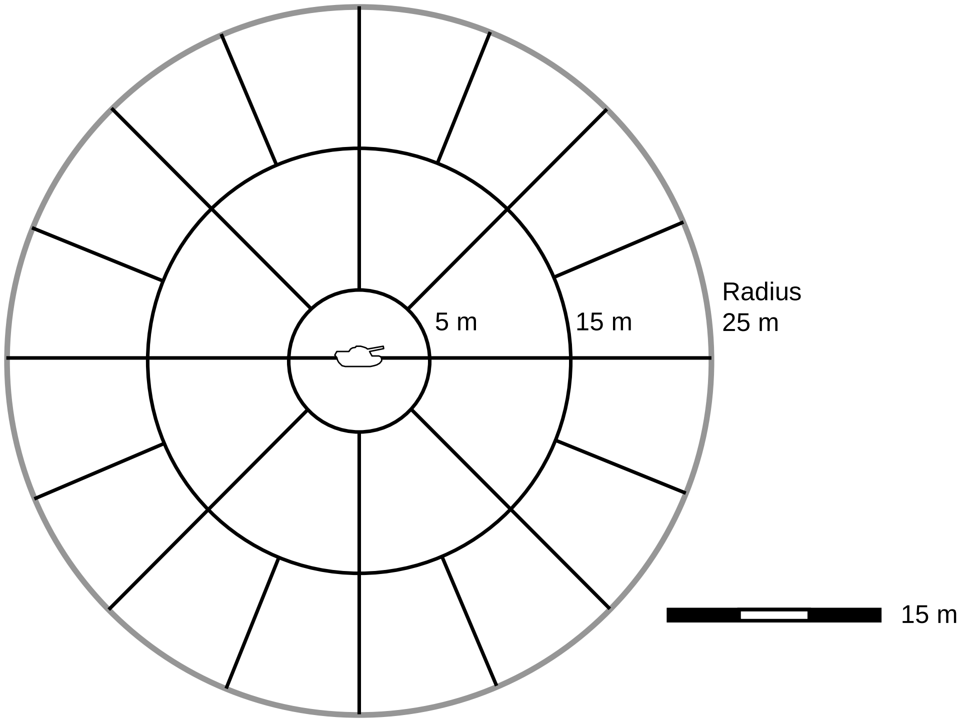


Figure 30. Segmented halo sampling pattern surrounding a tank target at a live-fire bombing range impact area.

Firing points

The highest concentration of the propellant residues at anti-tank ranges is behind the firing line. To estimate the total mass of residue in this area, a single 100-increment sample is recommended in a rectangle 30 m wide and running the entire length of the firing line (Fig. 31a). This same design can be used just in front of the firing line. If a more detailed characterization is desired, divide the area behind and in front of the firing line into three 10-m-wide rectangles along the entire length of the firing line and collect a 30-increment sample within each area (Fig. 31b). Because residues are deposited at the surface and little surface disruption occurs, it is recommended that firing point samples be taken from the top 2.5 cm.

To assess whether subsurface migration of dissolved propellant-related compounds has occurred, the same strategy as presented in the hand grenade range is recommended. Sampling locations should be 5–10 m behind the firing line at the most heavily used firing position.

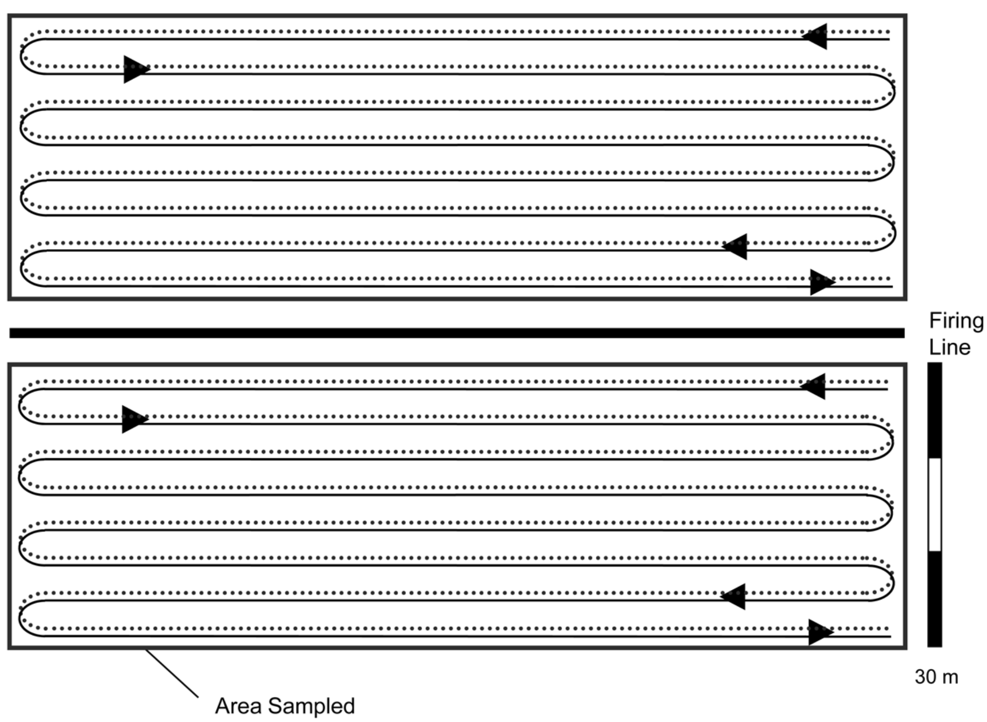
Artillery Ranges

Away from firing points and targeted areas

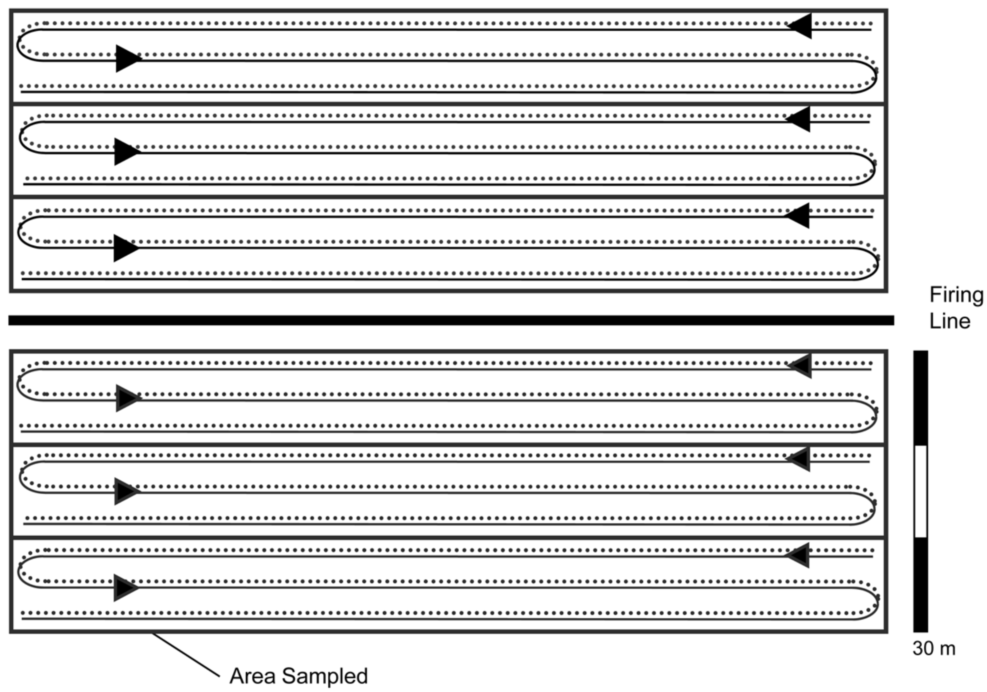
Sampling studies performed in the region 100 m from an established firing position to within 500 m of targets or heavily cratered areas have generally not found any measurable concentrations of energetic compounds (Ampleman et al. 2003a; Thiboutot et al. 2003, 2004; USACHPPM 2001, 2003, 2004, 2005; ME. Walsh et al. 2001). Thus, it is not recommended that sampling be conducted in this area. If it is decided that this area needs to be sampled, a square sampling unit sized 50 × 50 m or larger should be chosen if no surface anomalies are observed, and a 100-increment sample should be collected from the top 5 cm. Alternatively, if the sampling plan requests that a qualitative reconnaissance (visual inspection) be performed in this area, it is recommend that a MIS strategy with widely distributed collection points accompany this activity. When sampling large areas (> 10,000 m^2), global positioning systems could be used to help locate evenly spaced positions where individual increments will be collected. This is particularly important in adverse terrain with large changes in elevation and/or dense vegetation.

Impact areas

For areas with a defined target (or target debris), it is recommended to take a 100-increment sample from the top 5 cm of a 50- × 50-m square area centered on each target using the systematic-random design (Fig. 22). If rounds have undergone low-order detonation or chunks of energetic residues are visible and identified by field screening methods, mark a 10- × 10-m sampling unit or smaller sampling unit centered on each of these areas (Fig. 32). Then, qualified personnel should remove all visible pieces of MEC. In some cases, a UXO that cannot be moved may also be present in the sampling unit. This item and any other magnetic anomalies should be avoided. Once these tasks have been completed, a 30-increment sample from the top 5 cm of soil should be collected.



a. Pattern to collect two multi-increment samples in a single 30-m wide sampling unit.



b. Pattern to collect multi-increment samples in three 10-m-wide sampling units.

Figure 31. Strategies for collecting multi-increment samples in rectangular sampling units behind or in front of a firing line at an anti-tank range.

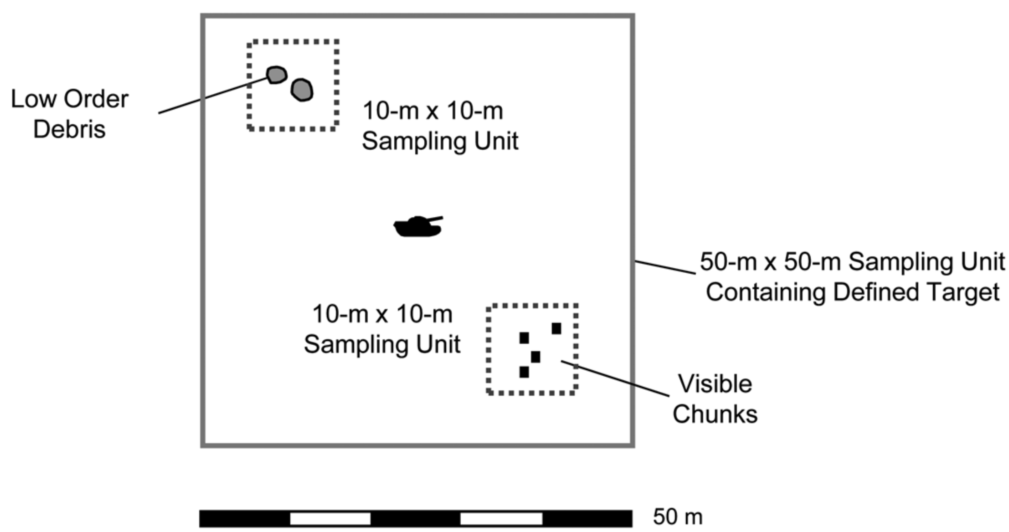


Figure 32. Sampling unit for collecting multi-increment sample surrounding a defined target at the impact area of an artillery range.

For heavily cratered areas, the area of concern should encompass at least 95% of the craters and a 20-m buffer zone (Fig. 33). These areas can be very large, depending on several factors such as placement of targets, training objectives, and age of the training facility. The recommended size of sampling units within this area is 50 × 50 m (or smaller) and a 100-increment sample from the top 5 cm should be collected in each unit. In the event that a low order detonation is found within a sampling unit, or chunks of energetic residues are visible, then a 10- × 10-m or smaller sampling unit can help identify areas where remediation may be necessary.

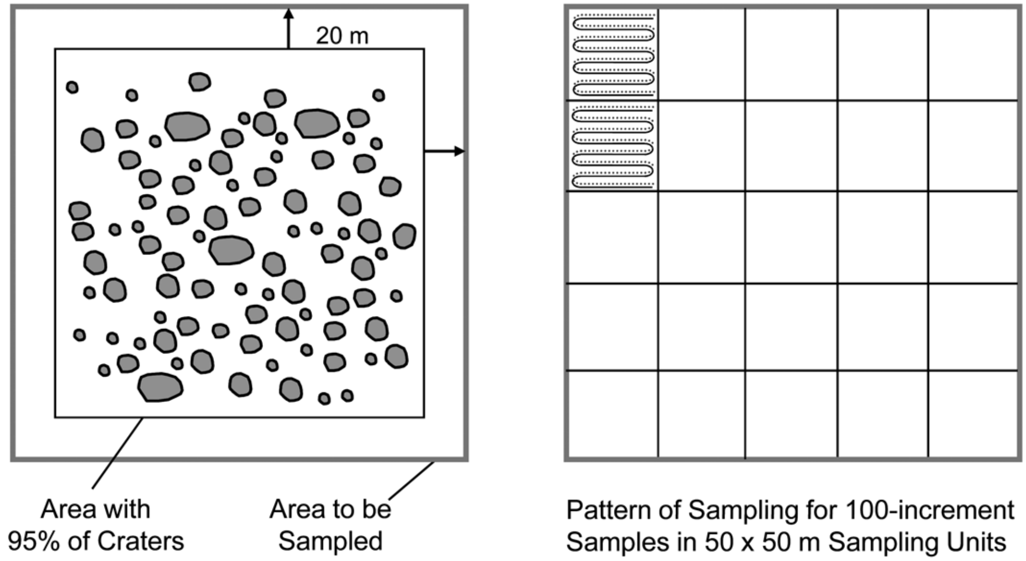


Figure 33. Example of sampling strategy at a crater field section of an artillery-mortar range impact area.

Profile sampling is recommended only in areas where low-order detonations have been found. As before, it is recommended to collect at least five profile samples, then combining the individual depth intervals (0–10 cm, 10–20 cm, and 20–30 cm) to form a single five-increment sample for each of these depths (Fig. 29). These samples establish the depth to which residues have been mixed into the soil profile, not to determine the average concentration for a subsurface layer over a large area. To achieve this second objective, 30–100 increment profile samples are needed, which clearly is unrealistic for profile samples. At the present, there are no established procedures to adequately characterize the subsurface. For depths below 30 cm, a surface geophysical survey may not be sensitive enough to detect UXOs, so down-hole clearance should be performed.

Firing point areas on artillery-mortar ranges

Most of the propellant residue deposition at mortar or artillery firing locations occurs in front of the gun tube. However, residue can accumulate on the surface at detectable levels up to 100 m downrange (Pennington et al. 2002, M.R. Walsh et al. 2006). Within firing areas where a variety of gun arrays are used, gradients in concentrations of energetic residues become obscured. However, they may exist downrange from the edge of the firing area. Within the firing area, sampling units of 50 × 50 m or smaller can be used for collecting 100 increments from the top 2.5 cm (M.E. Walsh et al. 2004, 2005). Therefore, to adequately characterize a firing point, which often covers several acres, multiple sampling areas would need to be defined and sampled.

At an established firing line or along the perimeter of the firing area, samples can be collected in rectangular sampling units to assess the downrange gradient parallel with the direction of fire. For each rectangular sampling unit, a 30-increment sample of the top 2.5 cm should be collected (Fig. 31b).

Sometimes, excess propellants are burned onsite at firing points after training exercises. These areas can be easily identified by the black soot on the ground created by the burned propellant residues. When a location that has been used to burn excess propellant is found, this area should be treated as a separate sampling unit. A 30-increment sample from the top 5 cm should be collected within a 10 × 10-m or smaller area centered on the location to quantify the concentration within this higher source zone. Sometimes, these areas are located within a firing point area and may not be distinguishable. If this is the case, concentrations of energetic compounds in replicate samples may vary substantially.

Profile sampling would only be recommended at a heavily used fixed firing point or directly beneath a location where propellant was burned on the ground surface. At a fixed firing point, profile sampling should be performed using our recommended strategy within 5 m of a mortar firing point and within 10 m of a howitzer firing point.

Bombing ranges

Surface sampling studies were conducted on two bombing ranges. At one range, samples were collected around a fixed target position, and at the other range, in a large (tens of hectares) crater field. Based on these preliminary findings the sampling designs and strategy recommendations for an artillery impact range would also apply here. High-resolution orthophotography, range maps, and LIDAR (Light Detection And Ranging) images can be evaluated as forensic evidence to locate former targets and craters. Using this evidence, sampling units can then be established within the range. Groundwater contamination by explosives may indicate the location of former targets (Bordeleau et al. 2007).

OB/OD ranges

To sample a range where open detonation or open burning is performed, divide it into 10 × 10-m sampling units and collect a 30-increment sample from the top 10 cm of soil from each (Fig. 34). Profile samples should also be collected in areas where the surface has been discolored or where demolition craters had been located in the past. Depth increments from at least five profile samples should be combined in a manner similar to that recommended for other ranges (Fig. 29). In this case, however, the sampling depth should extend below 4 m and perhaps continue to the groundwater table. For depths below 30 cm, down-hole clearance should be performed at 20-cm intervals.

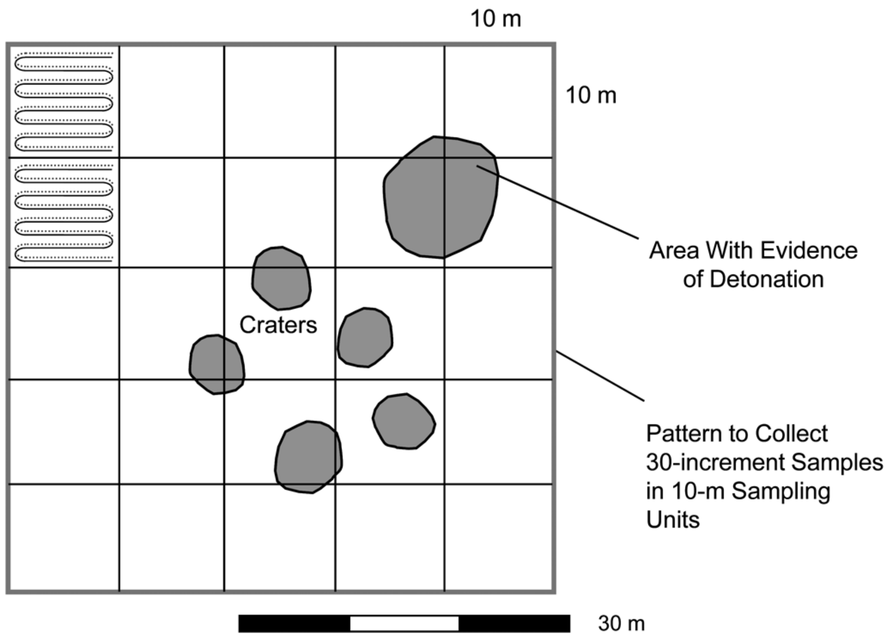


Figure 34. Recommended sampling units for collecting multi-increment samples at a detonation range.

Small arms ranges

Propellant and metal residues at firing points

Results from sampling experiments indicated that almost all of the propellant residues at small arms ranges were deposited within 10 m downrange of the firing line and within the top 5 cm of soil. For machine gun ranges or sport fire ranges, this distance might be extended to 20 m. To sample these ranges, 100 increment MI samples are collected from the firing line to a distance of 10 m (or 20 m for machine gun or sport fire ranges) from the firing line along the full width of the range. The sampling depth should be 5 cm. See Appendix A5 that describes an example site investigation of a small arms range using MI sampling techniques.

Metal residues at berm

Previous work has demonstrated that the entire berm face can be considered a sampling unit. Typically, the berm face is several meters high and several hundred meters long. To sample these ranges, 100 increment MI samples are collected from the berm face in a manner similar to Figure 31b. The sampling depth should be 5 cm.

Sample splitting in the field

Hewitt et al. (2009) evaluated if samples could be split in the field to minimize the mass of sample shipped to the laboratory without loss of sample integrity. Samples from five different ranges were placed in stainless steel bowls, the contents stirred with a stainless spoon to mix the contents as well as possible in the field, and divided into 5 or 7 equal splits. The entire < 2-mm fraction of each split was extracted and analyzed. There were 10 samples studied; within those samples, 20 split values were compared to the total analyte concentration. The median RSD value among replicate splits was about 40%; maximum values were in excess of 100%. Thus field splitting introduces unacceptable error and is not recommended. The entire sample should be shipped to the laboratory for processing and analysis. If regulators want to split samples for QA purposes, the samples should be split at the laboratory after the entire sample has been processed (Hewitt et al. 2009).

Laboratory sample processing for soils to be analyzed for energetic constituents

After soil samples are collected, they are generally sent to a commercial analytical laboratory to determine the concentrations of energetics present. Analytical labs use solvent (acetonitrile) to extract the energetic residues from the soil sample, and a small portion of the acetonitrile extract is analyzed by chromatography, usually using SW-846 Method 8330 (US EPA 1994). Because of the expense associated with the purchase and eventual disposal of acetonitrile, the minimum volume of acetonitrile is used for soil extraction. Consequently, only a small subsample is extracted rather than the entire soil sample. Unfortunately, the common practice has been to remove a small portion of the soil sample from the top of the jar. The remainder of the sample (often greater than 90%) was never processed, or even removed from the jar. Any replicate analysis for this sample also came from the same small portion of soil that was removed and air dried. The question of how well this small subsample represents the total sample was generally not evaluated.

In most cases, MIS from training ranges will contain very few energetic particles or propellant fibers compared to the total mass of soil. For example, if the MIS contains one energetic particle in each 100 grams of soil, a typical analytical subsample (a few grams from an un-ground sample) will likely not contain the particle and result in a non-detect value. If the subsample contains the particle, the concentration will be very high, at a much higher concentration than actually exists in the MIS (Hewitt et al. 2009).

Hewitt et al. (2009) conducted a study to assess the variability of energetics determinations for replicate subsamples from 5 and 7 sample composites. They studied samples collected at five different training ranges including two impact areas, two firing points and a demolition range. After briefly stirring the contents of the jar, three replicate subsamples from 5-increment and 7-increment soil samples were obtained in a fashion similar to that used at commercial laboratories, i.e. a single scoop off the top. There were 37 possible comparisons, but in six cases, analysis of at least one of the subsamples failed to result in a measurable concentration above analytical detections limits. In the worst case, TNT concentrations among the three replicates varied from < 0.035 to 262 mg/kg. Among the 31 triplicates without non-detect results, the RSD ranged from 8.4 to 155%, with a mean RSD of 70.1% and a median of 61.7%. The entire sample was also analyzed in each case and compared to the individual subsamples. In 67% of the cases, the mean of the subsamples was biased low, compared to the bulk sample. In over half of these, the mean was less than 50% of the concentration in the bulk sample. This could be explained by settling of the energetic particles to the bottom of the jar during shipment and storage. Clearly, subsampling by taking a scoop off the top of a sample does not yield an accurate average concentration of the soil sample.

M.E. Walsh et al. (2002) studied the variability of subsampling after samples had been air dried and ground with a mortar and pestle as specified in SW846 Methods 8330 and 8095. Twelve 50-g subsamples were taken from three explosives-contaminated soils and analyzed; the RSDs varied from 47 to 264% for TNT and RDX. Most of this variability came from a few subsamples with substantially higher concentrations than the rest, probably due to the inclusion of a larger particle of energetic material. It is clear that grinding in a mortar and pestle does not effectively homogenize the soil, even when large subsamples (50 g) are used. When two of these samples were mechanically ground with a ring mill, the RSDs for similarly sized subsamples ranged from 1.3 to 3.5%, a huge improvement. Subsequent research by Walsh and co-workers found that grinding for 60 to 90 sec on a ring mill reduced particle size of samples from impact areas containing crystalline explosives adequately to produce a homogeneous sample (M.E. Walsh et al. 2002). However, for soil samples from firing points and OB/OD ranges containing fibers of propellant, five 60-sec grinding periods were necessary to adequately reduce the particle size (M.E. Walsh et al. 2007, Hewitt et al. 2007a). In both cases, a 10-g subsample built from 30 increments of the ground material should be extracted with 20 mL of acetonitrile.

These changes to the way samples are collected and processed have been described in SW846 Method 8330B (US EPA 2006). In addition to those discussed above, several other method modifications were needed to measure average concentrations of energetic residues in soils from training ranges and demolition ranges. Hewitt et al. (2007a) demonstrated the energetic compounds in samples that had been air dried and ground in a ring mill were stable for up to 53 days, and likely much longer. Walsh and Lambert (2006) found acetonitrile extraction on a shaker table was equivalent to using acetonitrile in an ultrasonic bath. M.E. Walsh et al. (2007) found the sieve size for removal of oversized material after air drying and before machine grinding needed to be increased to 2 mm (#10 sieve) because a large portion of the energetic particles was in the size fraction between 0.6 and 2 mm. This fraction would not have been included in the analysis of the material passing through the 0.6-mm sieve, as was specified in the earlier Method 8330.

Analytical determination

Method 8330 (US EPA 1994) specifies using HPLC-UV (HPLC with an ultraviolet detector), and this has been the most widely used analytical approach for detecting energetic compounds in soil samples from military sites. Another method used is Method 8095 (US EPA 1999) that employs the same sample-processing steps as Method 8330, but uses GC with an electron capture detector for determination. There is no reason that this method of determination could not be used with the sample processing steps specified in Method 8330B.

Two other methods that have been used for determination of energetic compounds in soil are SW846 Method 8321 and a method developed by Army Environmental Hygiene Agency that is now used by CHPPM and laboratories working for them (Bishop et al. 2003). Method 8321 is an HPLC-MS method and energetic analytes are not target analytes of this method. In addition, the sample processing steps outlined in this method are not appropriate for use with energetic compounds. Most of the time when Method 8321 has been specified, samples were processed according to Method 8330 and the extracts were determined by HPLC-MS.

Use of HPLC-MS for determination of energetic compounds is attractive because the MS can provide more unequivocal identification of analytes than those obtained via retention time matching. However, the instrumentation is more expensive, and is thus a more costly approach than HPLC-UV. As a part of the study conducted by Roote (2010), a direct comparison of determinations for the same extracts from soil samples from two training ranges were analyzed by HPLC-UV and HPLC-MS-MS. This included samples from an Air Force bombing range where TNT was the major analyte detected and from an antitank rocket firing point where NG was the major analyte detected. In both cases, the reproducibility for the HPLC-UV was slightly better than for the HPLC-MS-MS, but overall, both methods provide similar detection for the target analytes. HPLC-UV and HPLC-MS-MS are both included within SW846 Method 8330B.

Overall recommendation for sampling and analysis

It is recommended that soil samples from training ranges be collected and analyzed according to the procedures specified in SW846 Method 8330B. MIS is a robust method for collecting representative samples from a sampling unit that yields reproducible and unbiased estimates for energetic compounds. Often replicates collected in this fashion will be normally distributed allowing the use of simple statistics to obtain estimates of the remaining uncertainty in mean concentration estimates for exposure areas.

The entire sample collected in the field should be shipped to the laboratory. The laboratory should air dry and process the entire sample before subsampling. The dried sample should be passed through a 2-mm sieve to remove over-sized particles and the material less than 2-mm should be mechanically ground using a ring mill to reduce particle sizes of soil and energetic compounds. If larger pieces of explosive or propellant are observed, they should be weighed and noted. Subsampling should be conducted on the ground material using the MIS approach as well to build a 10-g subsample that should be extracted with 20 mL of acetonitrile. The resulting extracts should be determined using the method outlined in SW846 Method 8330B, using either HPLC-UV or HPLC-MS-MS. If HPLC-UV is used, identification of target analytes must be confirmed using the second column as specified in the method.

Metals and other potential contaminants of concern

Other chemicals besides energetic compounds and lead are potentially present at military ranges. The only extensive study conducted looking for constituents other than energetic compounds is the work at MMR (Clausen 2005, Clausen et al. 2004). The MMR studies have included the sampling of soil, surface water, sediment, and groundwater. The areas investigated were artillery/mortar firing points and an impact range, anti-tank rocket firing points and targets, WWII era grenade courts, OB/OD areas, maneuver training areas, and contractor test ranges. In addition to the analysis for the common energetic compounds, an expanded list of metabolites of RDX such as hexahydro-1,3-dinitroso-5-nitro-1,3,5-triazine (DNX), hexahydro-1-nitroso-3,5-dinitro-1,3,5-triazine (MNX), and hexahydro-1,3,5-trinitroso-1,3,5-triazine (TNX) have been targeted (Table 21). Also, non-energetic constituents were looked for such as MTBE, EDB, dioxin, furans, polychlorinated biphenyls (PCBs), polychlorinated naphthalenes (PCNs), herbicides, pesticides, dyes, metals, volatile organic compounds (VOCs), and semi-volatile organic compounds (SVOC). VOC and SVOC samples analyzed by GC/MS were intensely scrutinized for tentatively identified compounds (TICs) (Clausen et al. 2004).

Table 21. Target analyte list for MMR.

Target Analytes		
volatile organic compounds (VOCs)	polychlorinated biphenyls (PCBs)	nitrate/nitrite-nitrogen
methyl tert-butyl ether (MTBE)	dioxins	ammonia-nitrogen
ethylene dibromide (EDB)	furans	total organic carbon
semi-volatile organic compounds (SVOCs) including polyaromatic hydrocarbons (PAH)	polychlorinated naphthalenes (PCNs)	Dye Disperse Red 9 (methylaminoanthraquinone)
herbicides	white phosphorous	Dye Disperse Violet 1 (1.4- diaminodihydroanthraquinone)
pesticides	perchlorate	Yellow Dye (benzanthrone)
standard metals as well as antimony, molybdenum, and titanium	cyanide	Dye Vat Yellow 4 (dibenzochrysenedione)
radionuclides	phosphate-phosphorous	Dye Solvent Green 3 (1,4-di-o-toluidine-9,10-anthraquinone

Samples were also analyzed by GC/MS and lists of tentatively identified compounds (TICs) from VOC (volatile organic compounds) and SVOC determination (semi-volatile organic compounds) were intensely scrutinized (Clausen et al. 2004).

Compounds detected at MMR by media type and range usage varied (Table 22). An extensive discussion of the potential contaminants of concern for both soil and groundwater at MMR, as well as the materials fate-and-transport properties, are presented in Clausen et al. (2007).

Artillery and mortar firing positions

Artillery and mortar propellants contain a number of chemicals in addition to 2,4-DNT including di-n-butylphthalate, diphenylamine, and ethylcentralite, each ranging from 0 to 10 percent depending on the mixture specifications. Barium nitrate, potassium nitrate, potassium sulfate, and graphite, at 0–1.5 %, also are present in some propellant mixtures. Diphenylamine is present is some propellants and can be transformed to N-nitrosodiphenylamine in storage and perhaps during combustion (Stine 1991, Espinoza and Thornton 1994). At MMR 2,4-DNT and 2,6-DNT, diethyl phthalate, di-n-butyl phthalate and N-nitrosodiphenylamine were consistently detected in surface soil at the 37 artillery and mortar firing positions sampled (Clausen et al. 2007, Table 23). Although metals have been observed in surface soils, neither they nor any of the identified constituents listed above, other than the DNTs, were detected in the 20 monitoring wells installed at eight locations within the firing position or in downgradient locations.

Table 22. List of compounds detected in soils and groundwater at the MMR ranges.

Compound Class	Detected Constituent	Potential Contaminant of Concern	
		Surface Soil	Groundwater
Explosives	Yes	Yes	Yes (RDX, HMX, ADNT, DNTs)
Propellant energetics	Yes	Yes	No
VOCs	No	No	No
SVOCs	Yes (OB/OD & Firing Points)	Yes	No
Metals	Yes (SAR berms)	Yes	No
Radionuclides (DU)	No	No	No
Pesticide/Herbicides/PCBs	No	No	No
Dioxin/Furan	Yes (OB/OD)	Yes	No
PCN	Yes (Impact Area)	Yes	No
WP	Yes (limited)	Yes (anoxic environments)	No
Perchlorate	(Firing points, Impact Areas & OB/OD)	No	Yes
Dyes	Yes (Maneuver Areas & OB/OD)	No	No
DU = depleted uranium; SAR = small arms range			

Artillery and mortar impact area

As previously discussed, energetic compounds are found in the impact area surface soils near targets and low-order detonations as well as sometimes in groundwater. Three additional constituents (perchlorate, PCNs, and metals) warrant a brief discussion.

Perchlorate is used in the spotting charge for artillery ordnance when a HE warhead is not utilized. Low-levels of perchlorate, < 50 µg/kg, have been detected in surface soils as well as in groundwater at MMR (Table 23). As discussed in Clausen et al. (2007) perchlorate is rapidly dissolved, does not sorb to soil components, is largely recalcitrant, and thus it is highly mobile. The high solubility and ease of dissolution prevents persistent build-up in soil, but can potentially produce groundwater contamination.

Some inert artillery and mortar projectiles also contain a wax filler, referred to as Halowax (Falandyz 1998), in the warhead as a weight replacement for HE. Halowax contains polychlorinated napthalene (PCN) compounds and these were detected in a number of surface soil samples from the Impact Area and contractor test ranges at MMR. The fate-and-transport properties of

Table 23. Analytes identified in various media at MMR by range activity.

Range Activity/Location	Media	Analytes Identified
Artillery and Mortar Firing Points	Soil	DNT, phthalates, N-nitrosodiphenylamine
	Groundwater	None
Artillery and Mortar Impact Area – Away from Targets	Soil	None
	Groundwater	None
Artillery and Mortar Impact Area – Near Targets	Soil	RDX, HMX, TNT, metals, perchlorate, PCNs
	Groundwater	RDX, HMX, perchlorate
Anti-Tank Rocket Range Firing Point	Soil	NG
	Groundwater	None
Anti-Tank Rocket Targets	Soil	RDX, TNT, metals
	Groundwater	None
OB/OD and EOD Demolition Areas	Soil	RDX, HMX, TNT, DNT, aDNT, perchlorate, metals, dioxins, furans
	Groundwater	RDX, HMX, TNT, aDNT, perchlorate,
Maneuver Training Areas	Soil	None
	Groundwater	None
Small Arms Ranges Firing Points	Soil	NG, 2,4-DNT
	Groundwater	None
Small Arms Range – Range Floor	Soil	None

	Groundwater	None
Small Arms Ranges Impact Berm	Soil	Metals (Cu, Pb, Sb, W, Zn)
	Groundwater	None
Note: In the case of metals identification refers to detection at a concentration above background values.		

PCNs indicate that they are not likely to be mobile and they were not detected in groundwater at MMR (Clausen et al. 2007).

Metals were also detected in all soil samples collected from the Impact Area at MMR (AMEC 2001a, b). However, it is difficult to determine whether the metals detected were from military activities, were anthropogenic metals derived from atmospheric fallout, or were from natural metals even when comparisons are possible with background samples. Most of the metals detected in the Impact Area were at concentration levels on par with background levels. In a few cases, elevated metals concentrations above background seemed to be the result of military activity. The metals falling into this category include aluminum, iron, molybdenum and possibly manganese and nickel. However, when the spatial distribution of the metal concentrations were mapped in relation to the target locations, there were no obvious patterns (AMEC 2001b).

Depleted uranium may have been used at a few military sites in the USA, but it has not been investigated and will not be discussed in this document.

Anti-tank rocket ranges

As discussed previously, NG is often found in surface soil at anti-tank firing points, sometimes at rather high concentrations. However, NG has not been detected in groundwater at MMR (Ogden 2000). Besides NG, no other compounds were observed in surface soil at the firing points other than metals, which were also observed at the target locations (Table 23). However, the metals concentrations in soil at the anti-tank range appear to be consistent with background levels (Ogden 2000).

OB/OD and EOD Detonation Areas

In addition to the energetic compounds previously noted at OB/OD sites, a wide variety of other constituents have been detected in surface soils at Demolition Area 1 at MMR. These constituents include low-levels of perchlorate, which were noted in the soil as well as groundwater (Table 23). Perchlorate is likely the result of burning of pyrotechnics, including fireworks. Other compounds identified in the surface soil include metals, dioxins, and furans. The dioxin and furans are presumably due to the burning of materials. Although metals were detected in groundwater, the concentrations were consistent with background levels and did not indicate the migration from surface soil. The dioxin and furans were not detected in groundwater.

Small arms ranges

As previously discussed, the energetic compounds NG and 2,4-DNT are often detected in surface soil at small arms range firing positions, and they were detected in soil at these ranges at MMR. Other than metals no other munitions-related constituents were detected in soils at small arms firing positions at MMR (Table 23). On the range floor, metal constituents such as antimony, lead, copper, tungsten, and zinc were slightly elevated and increased in concentration when approaching the berm face (Clausen et al. 2007). In contrast, at the berm face elevated concentrations of the metals antimony, copper lead, tungsten, and zinc have been observed (Clausen and Korte 2009) with concentrations in the 100s to 10,000s mg/kg.

Metals at other ranges

The casing materials for most artillery and mortar projectiles primarily consist of the metals iron and manganese, including copper and zinc in the rotating bands of artillery projectiles. The predominant metal in anti-tank rockets is aluminum. Metals have been observed in artillery and mortar impact areas and anti-tank rocket ranges near targets (Clausen et al. 2004). The observed concentrations were lower than the levels observed at small arms ranges.

Given the presence of elevated concentrations of metals at small arms ranges the focus of this section is on such ranges. A question exists on whether methodologies developed for energetics, Method 8330B, should be adopted and applied for metals constituents introduced to the environment as metal particulates. Similar to the energetic compounds, the metals are being deposited as solids so the same distributional issues applying to energetics may be relevant to the metals. Recently, research has been undertaken at CRREL to address this question.

MI Sampling Necessity

The first issue explored is the question of whether MIS is necessary when sampling for metals and, if so, how the sampling units should be configured. A study was undertaken where a small arms range berm was considered as a single sampling unit and sampled using a systematic random MIS design, a systematic random discrete sample design, a biased discrete sample design, and a biased large volume design (a portion of the berm is shown in Fig. 35). The sampling unit consisted of surface soils to a depth of 5 cm over an entire small arms berm face approximately 100 m long and 3 m high.

Data for seven discrete samples collected in a systematic random manner from the berm face shows elevated relative standard deviations (RSDs) for all metals with a low of 16% for iron to a high of 180% for copper (Table 24). Five metals (arsenic, chromium, molybdenum, nickel, and vanadium) were not detected at a detection limit of 15 mg/kg. Analyses of laboratory triplicates from sample B8 (B8-A, B8-B, and B8-C; Table 25) show that error (variability) attributable to

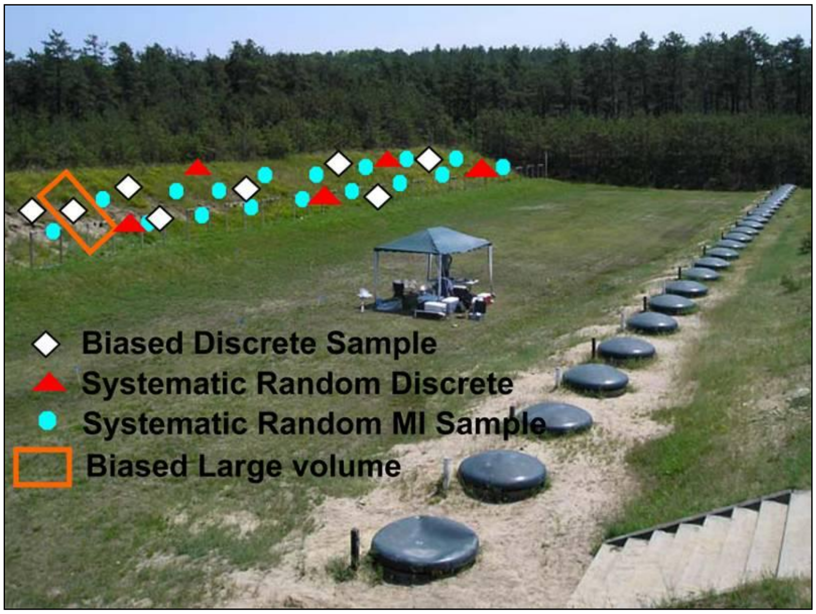


Figure 35. Schematic showing comparison of different sampling designs for a portion of a small arms range berm. Blue dots represent approximate locations where increments were collected to build MI sample. White and red symbols represent approximate locations of discrete samples.

Table 24. Systematic random discrete sample metal results (mg/kg) for samples B8-A through B14.

Element	Concentration (mg/kg)							Mean (mg/kg)	Std. Dev. (mg/kg)	% RSD
	B8-A	B9	B10	B11	B12	B13	B14			
Al	4,323	4,202	5,390	4,983	4,339	3,605	5,938	4,676	801	17
Ca	11,905	23,876	26,968	22,218	20,708	20,835	21,972	21,214	4,629	22
Cu	84	257	430	2316	29	24	109	462	830	180
Fe	5,691	5,630	6,811	6,646	5,628	4,866	7,774	6,116	999	16
Mg	602	793	962	974	733	723	1,065	839	162	19
Mn	41	38	54	54	39	42	90	51	19	37
Pb	277	345	590	549	264	720	370	445	175	39
Sb	16.4	<15	16.0	16.2	<15	16.6	<15	NA	NA	NA
Se	<15	<15	17.78	15.10	<15	<15	<15	NA	NA	NA
W	429	625	1,054	1,374	292	142	777	666	439	66
Zn	24.8	41.7	46.6	61.0	<15	16.5	35.4	37.7	15.9	42

NA – not applicable

Table 25. Precision of laboratory replicates of sample B8-A.

Element	Concentration (mg/kg)			Mean (mg/kg)	Std. Dev. (mg/kg)	% RSD
	B8-A	B8-B	B8-C			
Al	4,323	4,483	4,011	4,272	240	5.6
Ca	11,905	12,431	11,427	11,921	502	4.2
Cu	84	60	61	69	14	19.8
Fe	5,691	5,608	5,066	5,455	339	6.2
Mg	602	717	547	622	87	13.9
Mn	41	43	35	40	4.3	10.9
Pb	277	303	248	276	28	10.0
Sb	16.4	<15	<15	NA	NA	NA
Se	<15	<15	<15	NA	NA	NA
W	429	392	359	393	35	9.0
Zn	24.8	26.6	22.9	24.8	1.9	7.5
NA – not applicable						

laboratory subsampling, processing, and instrument variability is generally significantly less that the variability between the individual discrete field samples (Table 24). The variability between laboratory replicates in Table 25 reflects the combined error due to aliquot selection, sample preparation, and analytical (instrument) error (i.e. TEL + AE in eqn 2 of Appendix B, this document), and reveals the general magnitude of field sampling variability (TEF) in the total error.

Table 26 compares the mean results for the biased discrete, systematic random discrete, biased large volume, and multi-increment samples. The RSDs among replicates are presented in Table 27. In general, the mean concentrations of the discrete metal results are consistently higher than the MI sample results. Further, the RSDs for the biased discrete samples are lower than systematic random discrete samples. However, the RSDs for the MI samples are even lower than the discrete samples and little difference was evident between the 50- and 100-increment MIS.

Table 26. Comparison of mean metal concentrations for the different sampling methods.

Sample Type	Discrete		Large-volume Discrete	Multi-increment		
Sample Design	Systematic Random	Biased	Biased	Biased	Systematic Random	Systematic Random
Element	Concentration (mg/kg)					
Increments per sample	1	1	1	15	100	50
Al	4676	7147	4025	4377	4368	4473

As	<15	<15	<15	<15	<15	<15
Ca	21,214	23,385	12,969	20,166	13,230	13,150
Cr	<15	184	74	75	78	76
Cu	462	1,555	569	984	643	709
Fe	6,116	10,646	6,686	7,423	7,392	7,233
Mg	839	1134	691	822	720	720
Mn	51	79	43	51	46	46
Mo	<15	<15	<15	<15	<15	<15
Ni	<15	<15	<15	<15	<15	<15
Pb	445	1,182	952	945	339	357
Sb	16.3	31.4	25.4	23.3	15.8	15.2
Se	16.4	17.2	<15	<15	<15	<15
V	<15	16.2	<15	<15	<15	<15
W	666	1,479	581	1,247	787	783
Zn	38	135	32	41	32	43
Number of samples	**8**	**8**	**1**	**1**	**2**	**2**

Table 27. Comparison of relative standard deviations (RSD) or relative percent difference (RPD) for the different sampling methods.

Sample Type	Discrete		Multi-increment	
Approach	Systematic Random	Biased	Systematic Random	Systematic Random
Element	% RSD	% RSD	% RPD	% RPD
Increments per sample	**1**	**1**	**100**	**50**
Al	17	9	4	6
Ca	22	2	13	9
Cr	--	7	8	4
Cu	180	71	7	38
Fe	16	4	3	4
Mg	19	5	9	9
Mn	37	8	9	10
Pb	39	25	4	5
Sb	2.0	13.3	2	2
Se	11.5	7.6	NA	NA
W	66	5	14	13
Zn	42	89	21	0.3

Number of samples	8	8	2	2
NA = not applicable, RPD = relative percent difference				

The discrete systematic random and biased discrete are sample designs routinely used for sampling in the environmental industry. As these results indicate, a discrete sample yields results that are not reproducible and thus not representative of site conditions. In contrast, the systematic random MI sampling approach yielded results with significantly lower RPDs. Consequently, this sampling design will yield more reproducible results. Therefore, it is clear that MIS field sampling is necessary to reduce the sampling error to an acceptable level so that reproducible samples can be collected.

Sampling unit configuration

Small arms ranges consist of a firing point, range floor, berm face, and the back berm area (Fig. 36). A study of the metal distribution on several small arms ranges found differences between different areas (Clausen and Korte 2009, Clausen et al. 2007). Therefore, if the intent is to characterize the entire range, then at a minimum the sampling unit should consist of the firing point, range floor, and berm face, and in general, these should have different sampling units (ITRC 2003). In terms of the berm face, the sampling unit selected is dependent on the data quality objectives and should be determined during project planning. It is entirely feasible to treat the

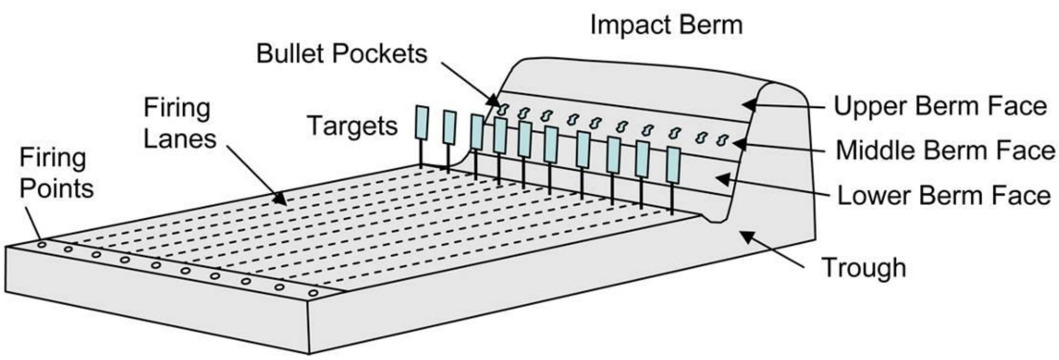


Figure 36. Typical configuration of a small arms range.

entire berm face as a single sampling unit. On the other hand, if information is desired from a more focused area it is possible to break the berm face up into several individual sampling units. Differences between metal concentrations at bullet pockets versus non-bullet pocket areas, upper, middle, and lower berm face locations, and between the middle of the berm face and lateral areas were evident (Clausen and Korte 2009, Clausen et al. 2007). There is no right or wrong way in configuring the sampling unit. Rather, the configuration is dependent on the study needs.

Sieving

Method 8330B for analysis of samples for energetic compounds calls for sieving of the soil sample to separate the sample into > 2 mm and < 2 mm size fractions. Analysis is performed on the < 2-mm fraction whereas the > 2mm fraction is not typically analyzed, since this material is not considered to be soil. At present, it is not known if the 2-mm size cutoff is appropriate for metals or if a different sieve size cutoff is appropriate. In the absence of data, the present EPA Method 3050B use of a #10 sieve, yielding a < 2-mm sample seems appropriate.

Previous work established differences in metal concentrations between < 2-mm and > 2-mm soil fractions collected from small arms ranges (Clausen et al. 2007). This was primarily due to the presence of intact bullets, bullet fragments, and metallic debris in the oversize fraction. In the case of a small arms range where tungsten projectiles were used, tungsten mass in the >2-mm sample varied significantly from sample to sample and represented anywhere between 20 to 80% of the total tungsten metal mass. So, in some cases, the < 2-mm fraction contained the bulk of the tungsten mass and in other samples the bulk of the tungsten was in the > 2 mm size fraction. However, the issue of whether the metal mass in the > 2-mm size fraction is environmentally important remains a research question.

Sample Pulverization

The next question that arises is whether the compositional heterogeneity of metal concentrations in soil is sufficiently variable to warrant pulverization of the soil through grinding. Results presented by Clausen et al. (2010a) for a sandy soil suggest if a RSD of 30% or less is acceptable then grinding may not be necessary. However, other preliminary data for samples from other ranges suggests grinding may be warranted. One of the important factors in whether particle size reduction is necessary in the preparation of samples containing particulate metals is the concentration of the metal of interest in the material being sampled. Because Fundamental Error and %RSD are inversely proportional to concentration, error tends to become very large when working with samples of low or moderate concentration, such as when approaching a regulatory decision limit or action level of a few hundred mg/kg or less (e.g. residential soil screening levels for lead). Achieving acceptable precision at such concentrations for analytical subsamples having mass of only a few grams requires particle size reduction (see Appendix B, Fundamental Error, Example C). An overarching determination on the necessity of grinding samples for metals analysis is not warranted at this time. However, if low metal concentrations are anticipated or levels close to a regulatory value then sample pulverization should be considered. It should be noted that an optimum grinding interval and identification of appropriate grinding equipment has not be completed. Another issue to consider when using metallic grinding apparatus is the possibility of the introduction of metal into the sample from the grinding equipment. This is discussed for one study in Appendix A5. Preliminary studies suggest this may be an important issue to consider if chromium, iron, manganese, or tungsten are constituents of interest. Research into this topic is ongoing and includes the degree of grinding necessary, comparison of different grinders, and grinding cross-contamination issues.

If trap and skeet small arms ranges are being sampled PAHs are possible contaminant of concern. Preliminary studies suggest this type of training activity results in particulate PAH deposition. Sample pulverization may be necessary for samples containing PAHs. However, the state of research on the optimum procedures for this class of compounds is less advanced than the research with metals. Given, the physical similarity between PAHs and propellant compounds it is suggested that the procedures developed for sample preparation of soils containing propellants be followed for samples containing PAHs.

Sample Digestion

The present EPA Method 3050B calls for digestion of 1 to 2 g of sample. Studies are ongoing at CRREL to assess whether this digestion mass is appropriate or whether a larger digestion mass is necessary for samples from military ranges. As discussed earlier, in the case of energetics, a larger extracted soil mass yielded a more representative and reproducible result.

Another research question related to sample digestion is whether different digestate solutions are warranted to improve metals recoveries. Method 3050B requires use of nitric acid to recovery the environmentally available metals and hydrogen peroxide to remove organics. Clausen et al. (2010c) found the addition of phosphoric acid to the Method 3050B digestate protocol was necessary to keep tungsten in solution. Low tungsten recoveries were observed when using only nitric acid. Consequently, digestion following Method 3050B was compared against digestion using stronger acids for the metals of interest at small arms range (Clausen and Korte 2009). Although, metal recovery increased with increasing digestion solution aggressiveness, the difference in results was not significant to change the interpretation of results. Therefore, Clausen and Korte (2009) recommended no changes to EPA Method 3050B for digestion. Only in the case where tungsten is expected and information is desired on the concentration and distribution should Method 3050B be altered by adding phosphoric acid to the digestate to improve tungsten recoveries. Additional work may be necessary for antimony and thallium due to poor recoveries using the existing methodology for Method 3050B.

Other Constituents

In regards to other constituents such as PCNs, SVOCs, dioxins, furans observed at some types of military ranges, the question remains whether MI sampling and sample processing protocols developed for energetic compounds need modification. MIS sampling and the sample processing in Method 8330B have been successfully used at an OB/OD site at Hill AFB for analysis of perchlorate (see Appendix A2). At present, research studies for other constituents have not been undertaken so the existing sampling and sample preparation procedures should be followed.

A case study in which MIS sampling was used to evaluate deposition of perchlorate by a Multiple Launch Rocket System is given in Appendix A4.

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Appendix A1. Case Study: Incremental Sampling of Sediments Contaminated with White Phosphorus

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Background Information

Eagle River Flats (ERF) is an Alaskan salt marsh that serves as a staging area for migrating waterfowl. The marsh, located in the upper Cook Inlet of Fort Richardson (Fig. A1-1), has also served as a U.S. Army artillery impact range into which howitzer, mortar, and rocket rounds have been fired since around 1950. In the early 1980s, high numbers of waterfowl carcasses were found at ERF by a U.S. Army biologist. Subsequent studies in the 1980s documented the extent of the mortality but did not reveal the cause. In 1989, use of ERF as an impact area was suspended due to the suspicion that residues from high explosives were the cause of the waterfowl deaths.

Figure A1-1. Aerial view of the 865-ha Eagle River Flats, with the Knik Arm of Cook Inlet in the background.

In 1990, we sampled ERF for high explosives (HE) residues, specifically RDX and TNT. Because dabbling ducks were the principal victims, we surmised that the poison resided as solid discrete particles in the sediments of shallow ponds where the ducks forage for food. Also, only a small portion of ducks that fed at ERF was poisoned, indicating that the poison was sporadically distributed. These conditions required that we collect many more samples than were collected by previous investigators. Our sampling did not reveal the presence of RDX or TNT; however, one sediment sample that gave off a vapor cloud and garlic-like odor indicated the presence of another munition that had been fired into ERF: white phosphorus (WP) (Racine et al. 1992). WP is used as an obscurant and was fired into ERF from mortars and howitzers.

During the initial investigations at ERF to determine the spatial extent of the contamination, surface sediment samples were collected at approximately 25-m intervals along transects through ponds in the marsh where ducks were observed to actively feed. This spacing was based on the radius of the area estimated to contain most of the fallout from the kinds of smoke projectiles that were commonly fired into ERF during training exercises (Shinn et al. 1985). At each sample location, several increments of surface sediment were collected from within a 1-m diameter area. Most of the samples from these transects contained low or undetectable concentrations of WP. Along transects where WP was detected frequently, concentrations varied widely, with relatively few samples having high concentrations (over 100 μg/g). When samples were taken at close intervals (1 to 5 m) around sample points with high WP concentrations, we again observed extreme heterogeneity, with non-detectable concentrations within a few meters of high concentration samples. This pattern of contamination led us to believe that most of the WP was located at the points of impact of WP projectiles.

Microscopic examination of high concentration samples revealed the presence of solid WP particles, most of which were 0.5 to 2 mm long, with some up to 6 mm long and weighing over 100 mg. These particles are much larger than the fine-grained silts and clays (95% finer than 0.02 mm) that make up the salt marsh sediment and could easily be selected by dabbling ducks searching for food or grit. The very low concentrations (less then 1 μg/g) detected in most samples were probably due to colloidal, dissolved, or molecular WP sorbed to sediment surfaces.

During the early 1990s, we determined the distribution and persistence of WP at ERF. These studies were followed by investigations of potential remediation and monitoring methods. Because WP readily oxidizes to phosphates when exposed to air, the sampling in 1998 was to use temporary pond draining by pumping because it was the most effective and least destructive remedial option. The plan was to pump water from contaminated ponds each summer until WP concentrations fell below 1 μg/g.

Incremental Sampling Methodology Development

The remediation objective was to remove WP from the surface sediments. The objective of sediment sampling was to estimate the mass of WP in the surface sediment of the ponds remediated by drying. If the WP had been evenly dispersed as fine particles over each pond, a set of discrete samples may have been sufficient to estimate the mass of WP over the treated area. However, the nature and distribution of the WP was much more complex.

Results from close-interval sampling at ERF and observations of impact points of 81-mm WP mortars at an upland site (Walsh and Collins 1993) indicated that the bulk of the WP available to feeding waterfowl (particles) was confined to very small areas (1 to 2 m diameter) punctuating much larger areas with little or no contamination. Subsequent studies at ERF indicated that these high concentration areas corresponded to the point of impact of WP projectiles, and that WP was not detectable or barely detectable outside of a 2- to 3-m radius.

Dabbling ducks were successful at finding WP, so we designed two sampling strategies that mimic feeding waterfowl. Dabbling ducks take numerous sediment increments as they feed in a pond. The poisoned ducks were those that dabbled within the very small diameter areas that contained milligram-size white phosphorus particles.

Grid multi-increment sampling method

The first method (grid multi-increment sampling) was developed in 1996 (Walsh et al. 1997) as an alternative to using penned sentinel ducks to determine if sufficient WP mass to poison waterfowl was present in a defined area. In this method, grid multi-increment samples are formed by combining sediment aliquots collected using an Oakfield corer (2 cm diameter) to a depth of 10 cm at the nodes of a 1.82-m-square grid. Spacing of the increments is designed to detect 2-m diameter hotspots (Gilbert 1987). A quadrat is used to maintain relatively precise subsample spacing (Fig. A1-2). Sampling unit grid size is generally 5.46 x 20 m, yielding 48 increments per multi-increment sample that combine to a final mass of 1–4 kg. A 200-g subsample of this field sample is later analyzed for white phosphorus. Based on the method detection limit for the analytical method (0.0002 µg/g), a single sediment increment with a white phosphorus concentration of 0.01 µg/g will yield a detectable white phosphorus concentration in the multi-increment sample. Lethal white phosphorus particles are generally associated with much higher concentrations (1 µg/g). Placement of the sampling unit grids is tailored to the area to be sampled. To sample small ponds, sampling unit grids are placed to maximize coverage of open water; to sample marsh areas that contains many small pools, sampling unit grids are placed at intervals (e.g., 30-m) (Fig. A1-3). When WP was detected within the marsh, then individual pools within and near the positive grids were sampled.

Figure A1-2. Sampling for white phosphorus in sediment using a 1.82-m square quadrat.

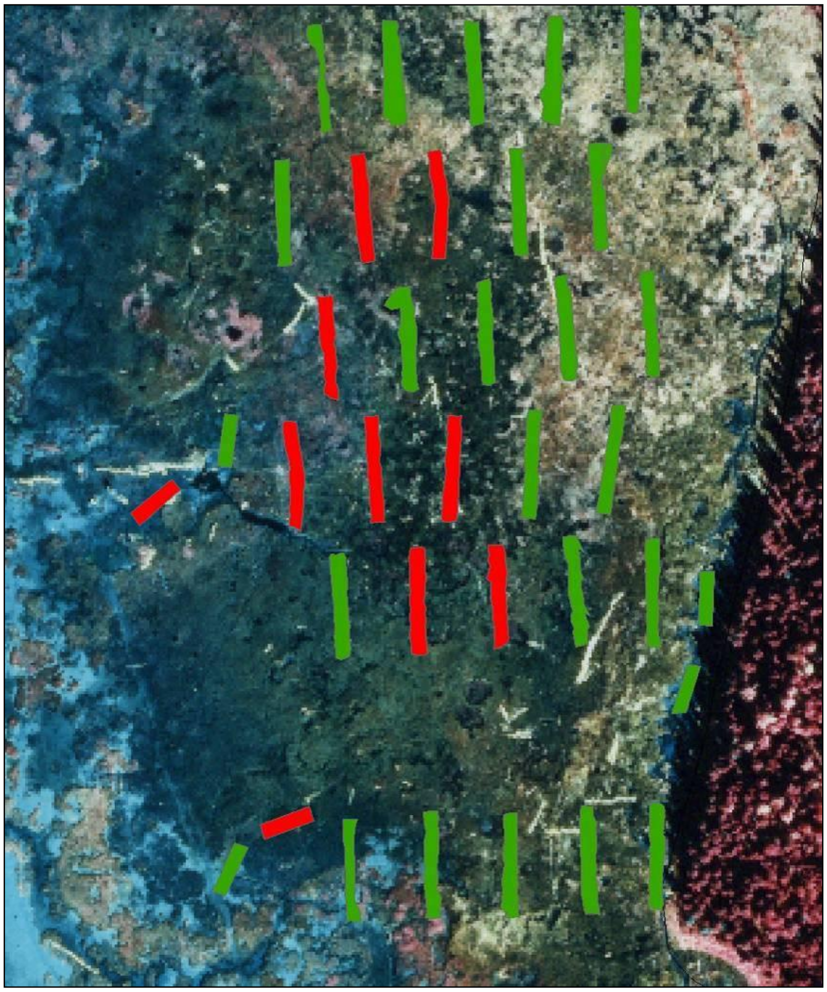

Figure A1-3. Rectangular incremental sampling areas spaced at 30 m intervals along transects across a bulrush marsh. Areas colored in red designate the presence of mg or greater quantities of white phosphorus.

Sieved multi-increment sampling method

The sieved multi-increment method is used in water-covered areas to sample large areas (entire ponds) or to intensively sample smaller areas by taking increments at least every half meter and placing them in a sieve bucket (0.59-mm mesh) (Fig. A1-4). The sediment is stirred and sieved underwater to remove the fine grain sediment. The mesh is sufficiently fine to also retain the ecologically relevant white phosphorus particles that, if present, would pose significant hazard to waterfowl.

Laboratory analysis of sediments for white phosphorus residues

All samples were stored at 4°C in the dark and were tightly sealed to prevent loss of moisture. Samples were analyzed using procedures described in EPA SW-846 Method 7580 [White Phosphorus (P_4) by Solvent Extraction and Gas Chromatography] (US EPA 1995). Each whole sediment multi-increment sample (1–4 kg) is thoroughly mixed by stirring. The wet sample is spread to a thickness of 1 cm, and a minimum of 30 small aliquots are taken to form a 200-g subsample. Sufficient water is added to form a slurry. Sieved multi-increment samples were not subsampled. Instead, the entire sample was transferred to a sufficiently large glass jar and enough water added to cover the sample.

The presence of white phosphorus is determined using solid-phase micro-extraction and gas chromatography. If white phosphorus was detected, the white phosphorus concentration is estimated by extracting the white phosphorus from the sample with solvent (isooctane) and analyzing the extract by gas chromatography (nitrogen–phosphorus detector). The gas chromatograph was calibrated daily using freshly prepared standards in the range of 1.8 to 88 µg/L. A linear calibration model was used to calculate the WP concentrations in the sediment extracts. If needed, extracts were diluted with isooctane to be within the calibration range.

a.) In a channel (May 2006) b.) Close-up of sieve bucket (August 2006)

Figure A1-4. Collecting sieved multi-increment samples.

Two Examples of Results

Table A1-1 shows the results for replicate samples obtained and processed using the grid multi-increment sampling method for five, 5.46 × 40-m sampling areas that stretched across a shallow pond (Walsh et al. 2000). Based on a sample mass of 4 kg and the lowest value established for the sampling area at the 100-m interval (18 µg/kg), a 1.6 mg particle of white phosphorus could have been present if only one increment among the 92 was from a hot spot. Using this logic one could make the assumption that at least one hot spot (location where a phosphorus round had incompletely detonated) was present in this pond, and particles large enough to cause water fowl mortality existed. This logic was used as a criterion to select which ponds needed to be drained with the aid of a semi-autonomous pump system (Walsh M.R. et al. 2000, 2006). Once drained, the surface sediments desaturated, which caused WP to sublime, a very effective and non-invasive remediation strategy for this hazardous compound in a fragile wetlands.

This particular pond was drained for several consecutive years and the sampling area with the highest average concentrations of white phosphorus was monitored by sampling annually (Table A1-2). After only a couple of drying seasons, the concentrations of white phosphorus in the top 10 cm of the sediments declined and remained below lethal levels for dabbling ducks.

Table A1-1. White phosphorus concentrations (µg/kg) in replicate samples along a transect bisecting a pond at 50 m intervals. Samples obtained in June, 1997.

Replicate	0 m*	50 m	100 m	150 m	200 m
1	< 0.2	0.32	18	2.7	0.37
2	< 0.2	0.49	61	3.5	0.42
3	< 0.2	0.61	69	4.0	0.47
4	< 0.2	0.70	73	4.1	0.67
5	< 0.2	0.76	85	4.9	0.83
* 92 increments per sample					

Table A1-2. White phosphorus concentrations found in grid multi-increment samples collected from 100-m sampling area in the middle of a pond. Data are shown for all field replicates.

Date	WP Conc. (µg/kg)
4 June 1997	18, 61, 69, 73, 85
4 September 1997	5.4, 6.3, 6.3, 6.5, 10
22 August 1998	5.4, 6.1, 7.4, 8.4, 44
15 September 1999	1.1, 2.1
16 August 2000	0.42, 0.67
11 September 2001	<0.2, 0.2
15 September 2003	<0.2, <0.2
25 August 2008	<0.2, <0.2
16 September 2009	<0.2, <0.2

Table A1-3 shows the results of sieved multi-increment samples collected within 5 m segments of water-filled channels. This sampling activity identified several locations where hot spots existed. Because the water in these channels could not be easily drained and the sediment dried, geotextile overlain with coarse gravel was used to cover these hot spots (Fig. A1-5). This barrier was added in the winter when this wetland was ice covered, using GPS coordinates

Table A1-3. Mass of white phosphorus in sieved incremental samples from drainage ditches. Samples were collected to define the horizontal distribution of white phosphorus in the channels.

Channel Segment #	Distance (m)	WP Mass (mg)
Segment 1	0 to 5	not detected
	5 to 10	0.0001
	10 to 15	not detected
	15 to 20	not detected
	20 to 25	not detected
	25 to 30*	122
	30 to 35	0.009
	35 to 40	0.005
	40 to 45	not detected
	45 to 50	not detected
	50 to 55	0.07
	55 to 59	not detected
	59 to 63	not detected
Segment 3	0 to 5	not detected
	5 to 10	not detected
	10 to 15	not detected
	15 to 20	0.00006
	20 to 24.25*	11.5
	24.25 to 28.5	1.9
Segment 5	0 to 5	2.3
	5 to 10	0.5
	10 to 15*	3.2
	15 to 20	not detected
	20 to 25	0.005
	25 to 30	not detected
	30 to 35	not detected
	35 to 40	not detected
	40 to 46.8	not detected
Segment 7W	0 to 5	not detected
	5 to 10	1.0
	10 to 15	1.8
	15 to 20	8.6
	20 to 25	168
	25 to 28.75	0.53
	28.75 to 32.5	0.002

* WP ordnance scrap was found within these intervals.

Figure. A1-5 Mounds of gravel covering hot spots of white phosphorus particles found in drainage channels and small ponds.

obtained when the ponds were ice-free. Multi-increment samples were collected over the next couple of years in a 0.5-m annulus around the perimeter of the gravel mounds to check that no ≥1 mg particles of white phosphorus particles were present (Bigl and Collins 2009). If white phosphorus was detected, more gravel was added to the mound, or the covered area was spread out, or both.

Summary

Today, firing of white phosphorus rounds into wetlands is prohibited by the U.S. and many foreign militaries (U.S. Army 2009). Members of the Fort Richardson Integrated Training Area Management team are writing an Environmental Impact Statement (EIS) to evaluate the return to year-round training activities, with a concerted effort towards avoiding areas containing white phosphorus. Independent of the EIS, the impact range has been decreased in size to avoid the disturbance of sediments in areas where white phosphorus is likely to remain buried deep within the sediments. To offset this constraint, the ERF program helped to establish new target arrays outside the treatment areas. Equally important, this area is no longer an imminent risk to migrating ducks and shorebirds; less than 10 white-phosphorus-related fatalities were reported for 2008, compared with about 1,000 in 1996 (CH2M Hill 1998). MIS was instrumental in mapping the distribution of WP and helping to remediate the hazard to waterfowl while continuing military training. Without this technique, it would have taken a couple more decades to reach these current levels of training sustainability and ecological remediation.

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Appendix A2. Case Study: Implementation of Method 8330B for Explosives Residue Characterization at the Utah Test and Training Range

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Introduction

The Utah Test and Training Range (UTTR) Thermal Treatment Unit is located approximately 50 miles west of Salt Lake City, UT. It is operated for the Ogden Air Logistics Center, Hill Air Force Base, Utah, by the 75 Civil Engineer Group, Explosive Ordnance Disposal Division. The facility covers an area of approximately 1500 acres and is permitted by the State of Utah through a State issued RCRA Part B Permit. Figure A2-1 shows the site layout with detonation and burn pads indicated. Treatment of most DoD owned reactive wastes or munitions are permitted at the facility, but the primary workload involves treatment of large rocket motors from 10,000 to 84,000 pounds net explosive weight (NEW) including C4 and D5 Trident, Minuteman, and Sprint solid rocket motors. Permitted operational limits are 320,000 lbs NEW for OB and 149,000 lbs NEW for OD for any single event. The Title V air permit limits OD operations to 84,000 lbs NEW/day and 6,552,000 pounds NEW/year. Items are detonated or burned above ground on specified pads that are constructed and maintained to facilitate the disposal operations.

Although the facility has operated for over 30 years, annual soil sampling has only been required since the RCRA Permit was issued in 2003. Prior to 2003, discrete sampling of soil occurred in 1989, 1991, and 2002. Discrete sampling was again conducted in 2004. The data from the soil sampling events are intended to support both the Human Health and Ecological Risk Assessments for the facility; however the large area and long and varied history of the site made characterization for these purposes challenging. Method 8330B techniques using *MULTI INCREMENT*® sample collection and pre-analysis sample preparation were first implemented in 2005 and have been used at the site through the 2009 sampling event.

Sampling Methodology

To characterize the site for surface contamination, the area was gridded into 100 m square grids as shown in Figure A2-1. Each grid cell is sampled by taking 100 incremental samples

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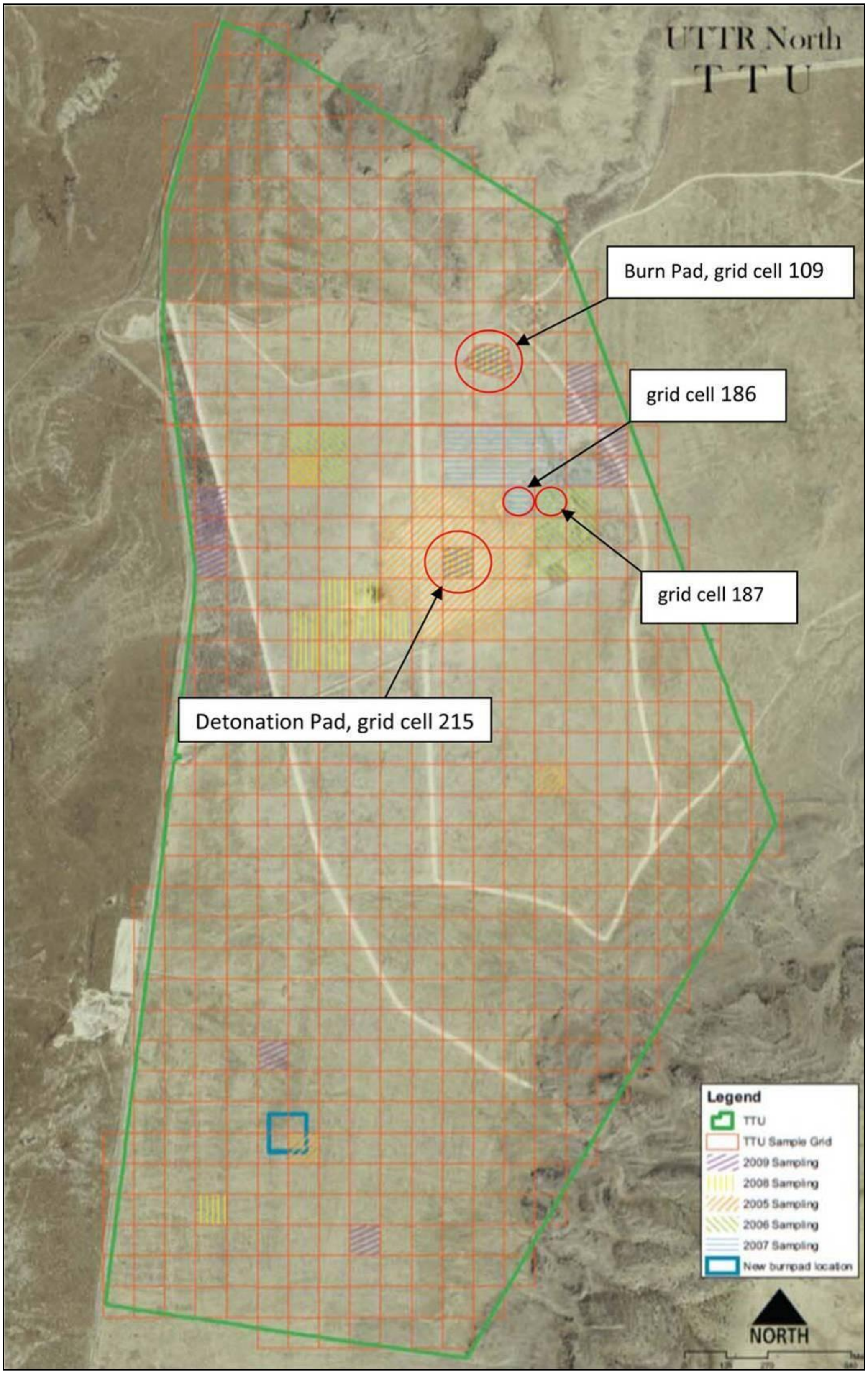

Figure A2-1. Utah Test and Training Range Thermal Treatment Unit with sampling grid and operational areas indicated.

in a systematic random sub-grid with an approximate spacing of 10 m between samples. Individual increments of approximately 20 grams are collected from the top 1-2 cm of the soil surface with pre-cleaned soil scoops and consolidated into a clean polyethylene bag. Samples are collected by teams of two people. Grids are pre-marked with stakes prior to the sampling event and each stake has an area location map attached to it so sampling teams do not need GIS support in the field. Samples collected in areas with excessive gravel are passed through a #10 sieve in the field to avoid collection of material greater than 2.0 mm.

Collected samples are shipped to the Hill Air Force Base Analytical Laboratory for pre-analysis sample preparation in accordance with Method 8330B. Air-dried samples are sieved through a #10 sieve and ground in a puck mill in 500-g batches. Sample grinding time has been reduced from five minutes (five, one minute grinds) to one minute to reduce metal (primarily chromium) contamination from the grinder. Chromium was detected in the 2005 samples. Ground samples are re-combined in their collection bags and then laid out on aluminum foil where 10-g samples are prepared from approximately 30 incremental scoops for analysis as specified in Method 8330B. Samples for metals (Methods 6010B, 6020 and 7471) and perchlorate (Method 6860) are prepared in a similar manner. Grinding and preparation of samples taken in 2005 and 2006 were conducted by the US Army Cold Regions Research and Engineering Laboratory (CRREL).

Results

Data from the 2005 to 2008 sampling events indicate that the 8330B methodology provides repeatable data applicable to human health and ecological risk assessments at the UTTR Thermal Treatment Unit (TTU). Analysis of soil samples has shown that the primary contaminants of concern at the site are perchlorate, HMX, and RDX. Distributions of these three contaminants at the TTU are shown in Figures A2-2, -3, and -4. All concentrations were below the site specific risk based concentrations of 713 mg/kg for perchlorate, 30,700 mg/kg for HMX, and 16 mg/kg for RDX.

Field triplicates or duplicates were collected and analyzed for selected areas each year. Some areas including grid cell 215, the center of the detonation pad, and grid cell 109, the primary burn pad, were sampled each year to evaluate year-to-year repeatability. These results are presented in Table A2-1. Within year repeatability was generally good with percent relative standard deviation (%RSD) values ranging from 3.7 for HMX on the detonation pad to 36.9 for perchlorate on the burn pad. Relative percent difference (RPD) values for field duplicates ranged from 0.0 for perchlorate duplicates on the burn pad in 2006 to 55.6 for perchlorate duplicates in grid cell 186, an area of infrequent mixed use between the detonation and burn pads, in 2007.

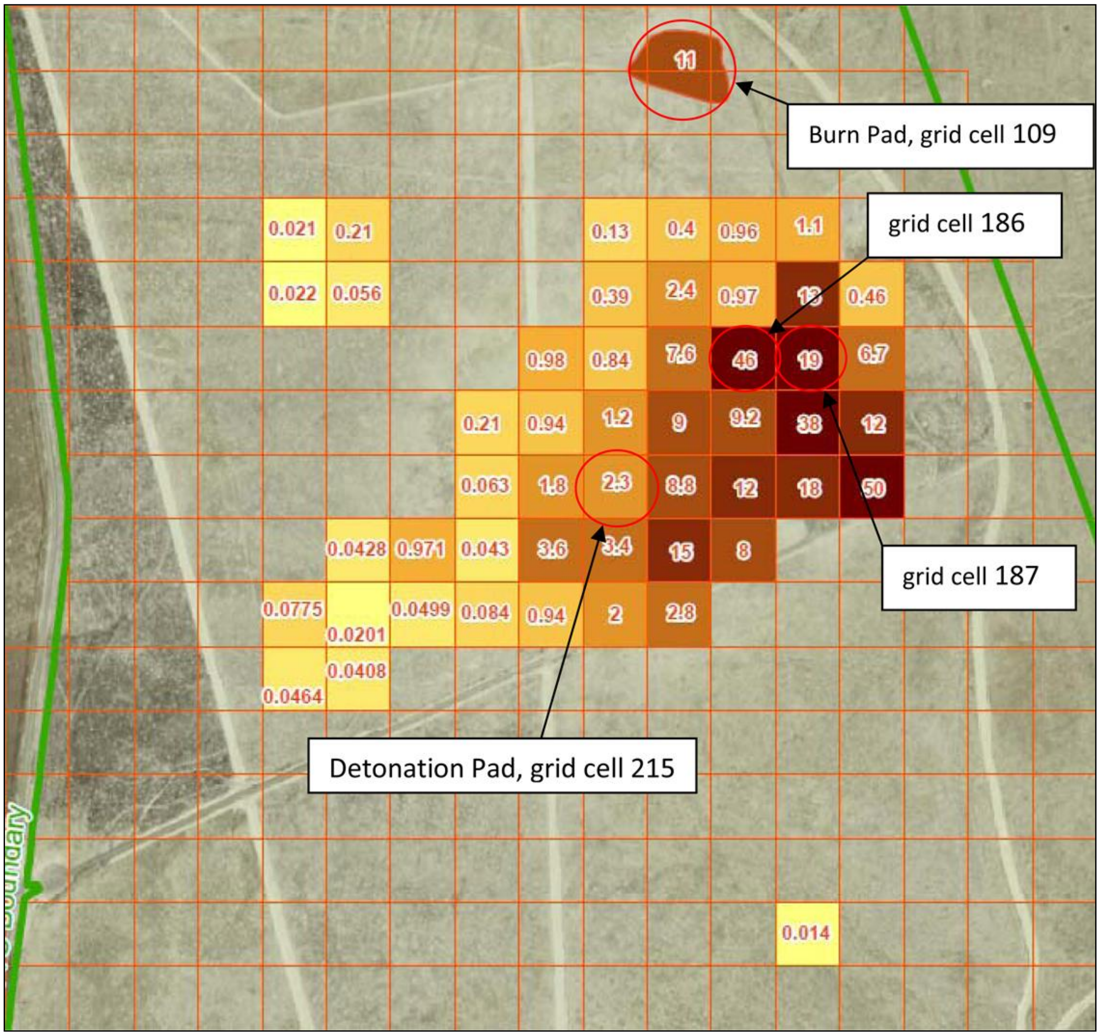

Figure A2-2. Perchlorate distribution at the TTU. Concentrations are given in mg/kg. For areas with repeated samples, values shown are for the first year's sampling event (with the exception of the Burn Pad, which was sampled as one unit for the first time in 2006).

Year to year repeatability (see Table A2-1) was also generally very good, given the fact that the area is an active disposal facility. Apparent exceptions include the jump in perchlorate concentrations on the detonation pad (grid cell 215) from 2005 to 2006 and a decrease in perchlorate concentrations on the burn pad (grid cell 109) from 2007 to 2008. If discrete samples had been collected, these variations would likely have been explained as inherent site variability, however because of the good within year repeatability that had been observed, further explanations were sought regarding site operations that may have contributed to these observed differences. It was discovered that a deflagration event had likely contaminated the detonation pad with perchlorate

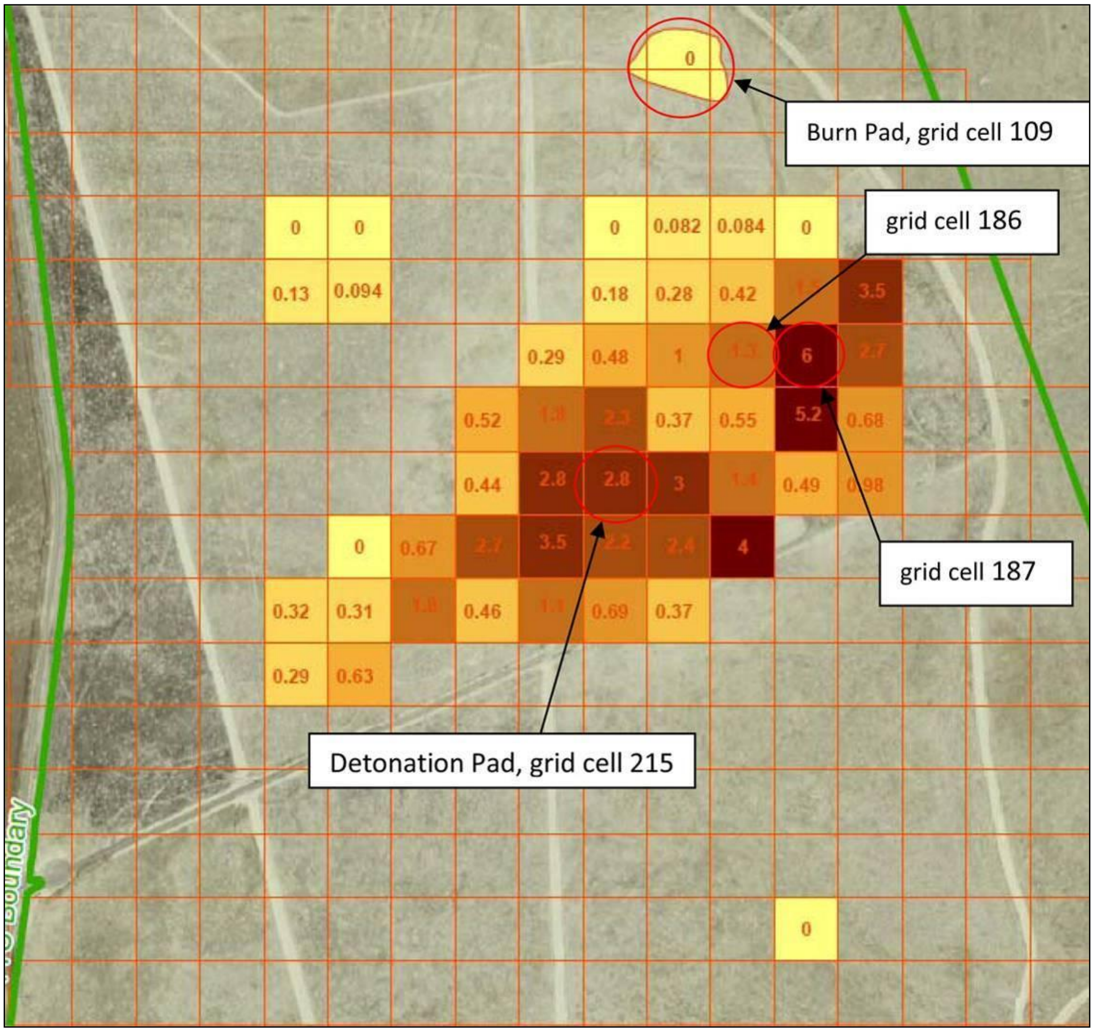

Figure A2-3. HMX distribution at the TTU. Concentrations are given in mg/kg. For areas with repeated samples, values shown are for the first year's sampling event (with the exception of the Burn Pad, which was sampled as one unit for the first time in 2006).

in 2006 causing elevated levels of perchlorate in 2006 and 2007 and the decrease in perchlorate concentrations on the burn pad is likely the result of decreased open burn operations during 2008. Repeated samples from grid cell 187 in 2006 and 2007 also showed fairly good agreement for all three contaminants.

In addition to field duplicates and year-to-year replication, laboratory replicates were also analyzed for HMX by independent laboratories, Severn Trent Laboratory (Denver) and CRREL, in 2005 and 2006. The samples were both prepared at CRREL prior to analysis. As indicated in Table A2-1, results from the two labs were found to be in agreement in both 2005 and 2006.

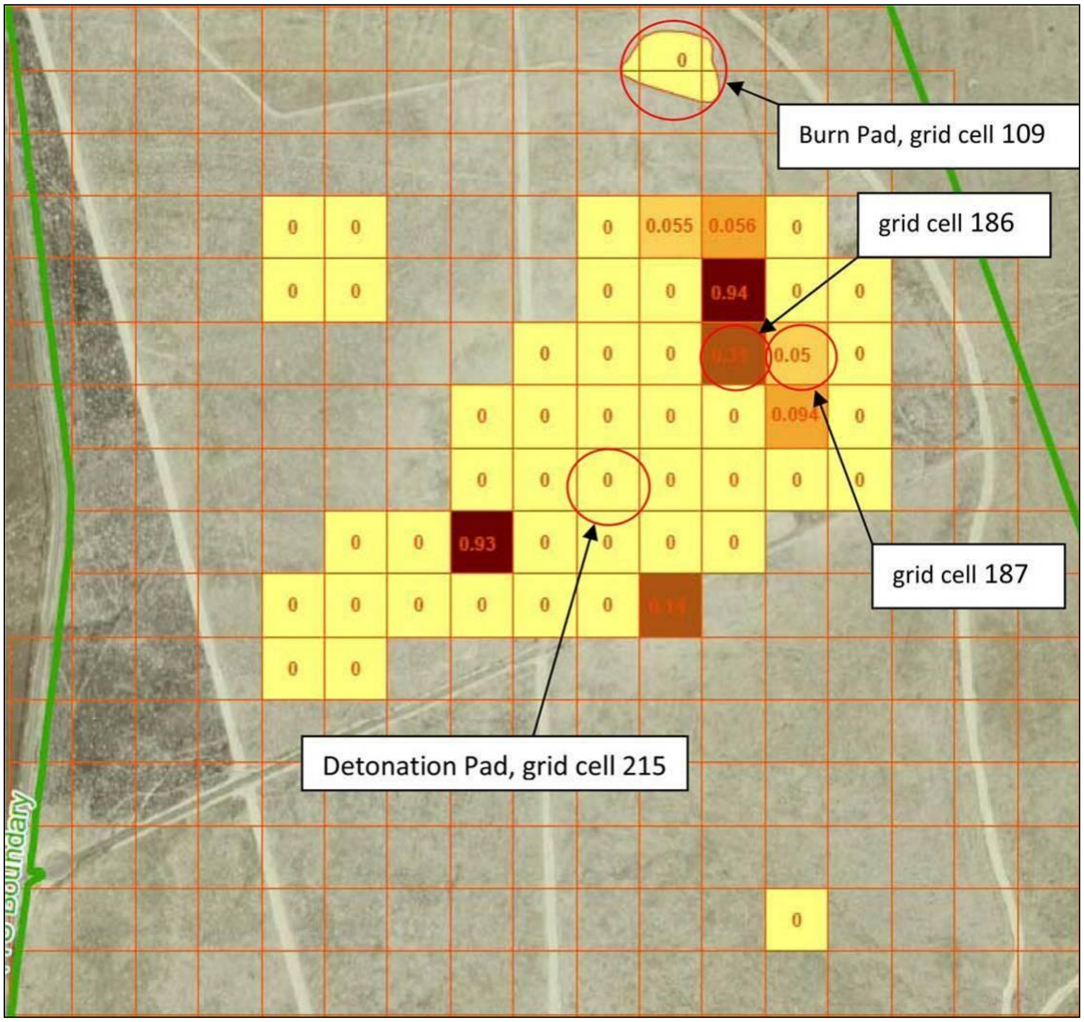

Figure A2-4. RDX distribution at the TTU. Concentrations are given in mg/kg. For areas with repeated samples, values shown are for the first year's sampling event (with the exception of the Burn Pad, which was sampled as one unit for the first time in 2006).

Sampling Costs

Annual costs of TTU soil sampling are shown in Table A2-2. These costs include preparation of sampling and analysis plans, sample collection, sample preparation (grinding), chemical analysis, and reporting. The elevated annual costs for 2008 were partially because dioxin/furan analysis was conducted on some samples. Average annual costs from 2005 to 2009 were \$0.28/m^2 if all duplicate and triplicate field samples are counted separately giving a total of 95 samples that have been collected and analyzed. If costs are calculated based on the total area that has been characterized, 78 grid cells or 780,000 m^2, then the average cost is \$0.34/m^2. This cost would be a conservative estimate for a similar program with the same level of quality assurance/quality control sampling.

Table A2-1. Results of replicate sampling at the UTTR. All Results are reported in mg/kg. Percent relative standard deviation (%RSD) is reported for triplicate samples and relative percent difference (RPD) is reported for duplicates.

Cell# [Area]	Contaminant of Concern	Repetition	Year			
			2005	2006	2007	2008
215 [det pad]	Perchlorate	1	2.3	68	61	9.4
		2	2.2	62	52	6.9
		3	2.1	86		
		%RSD or {RPD}	**4.5**	**17.3**	**{15.9}**	**{30.7}**
	HMX*	1	3.9 [4.3]	2.2 [2.3]	2.1	1.6
		2	3.4 [4.0]	2.2 [2.2]	1.6	1.5
		3	3.7 [4.2]	2.8 [2.9]		
		%RSD or {RPD}	**6.9 [3.7]**	**14.4 [15.3]**	**{27.0}**	**{6.5}**
109 [burn pad] †	Perchlorate	1	16	11	22	1.57
		2	16	11		1.5
		3	29			
		%RSD or {RPD}	**36.9**	**{0.0}**		**{4.6}**
186 [NE of det pad]	Perchlorate	1			46	
		2			26	
		RPD			**55.6**	
	HMX	1			1.3	
		2			0.79	
		RPD			**48.8**	
	RDX	1			0.31	
		2			0.40	
		RPD			**25.4**	
187 [NE of det pad]	perchlorate	1		19	28	
	HMX	1		6.0	6.0	
	RDX	1		0.11	0.05	

* In 2005 and 2006, split samples were analyzed for HMX by Severn Trent Laboratory, Denver (shown without brackets) and the US Army Cold Regions Research and Engineering Laboratory (in square brackets).

†The primary burn pad was divided into quarters for the 2005 sampling. 2005 values are for triplicate sampling of one of these quarters. Values for subsequent years represent the entire pad area.

Table A2-2. Costs of TTU soil sampling from 2005 to 2009.

Year	Cost*	# of cells**	cost/cell	cost/1000 m^2	cost/m^2
2005	$104,000	39	$2,667	$267	$0.27
2006	$43,000	15	$2,867	$287	$0.29
2007	$34,000	15	$2,267	$227	$0.23
2008	$46,000	13	$3,538	$354	$0.35
2009	$36,000	13	$2,769	$277	$0.28
Total/Average	$263,000	95	$2,822	$282	$0.28
Cost/cell excluding QA/QC samples (78 cells):			$3,372	$337	$0.34

* Total cost including plan preparation, sample collection, sample preparations, analytical, and reporting

**Total number of 100-m x100-m grid cells sampled including QA/QC samples

Conclusion

Method 8330B has been an effective method for soil characterization at the Utah Test and Training Range Thermal Treatment Unit. Discrete sampling used previously did not provide sufficient data to delineate the spatial extent of site contamination or to be effectively used in human health and ecological risk assessments. The MIS data has successfully delineated the areas of contamination and shown that exposure levels are far below the risk based levels of concern for the site. Method 8330B will continue to be used at the site to ensure for safe and sustainable operations.

Appendix A3. Case Study: Arnhem Antitank Rocket Range, Canadian Force Base Valcartier, Quebec

THOMAS JENKINS, BOWHEAD, RICHARD MARTEL, UNIVERSITY OF QUEBEC

The following is a summary of a series of studies conducted at the Arnhem antitank rocket range, located 35 km north of Quebec City at Canadian Force Base Valcartier, Canada. This range has been used continuously for target practice with antitank rockets since the 1970s. Site investigations have been conducted from May 1995 through 2006; they include soil sampling to assess the concentrations of energetic compounds in near surface soils and installation of ground water wells and groundwater sampling activities. Methods for sample collection, sample processing, and analysis employed at Arnhem have evolved as knowledge of the nature of energetic contamination has improved.

Site description

The Arnhem training range is situated on the north side of an east-west valley bounded by two mountains. The northern part of the range contains several target vehicles located on a steep, sloping boulder field. Several additional target vehicles are located at the base of the slope on a sand terrace. A hydrostratigraphic section of the region where the Arnhem range is located is shown in Figure A3-1. A regional aquifer underlies the site. While surface runoff flows to the west, the deeper ground water flows eastward.

Because of the difficulty in accessing the steep sloping region of the range related to UXO, all characterization has been conducted in the flat sand terrace area. In this area there are several target vehicles located approximately 100 m from the firing line where shoulder-fired rockets are launched (Fig. A3-2). The depth to ground water within this flat portion of the range varies from about 26 to 34 m below ground surface. An annual average of 135 cm of precipitation falls at Arnhem. However, 40 % of the precipitation (54 cm) recharges the aquifer.

Description of the munition fired at Arnhem

The munition fired at Arnhem for most of the lifetime of this range has been the M72 66-mm Light Anti-Armor Weapon (LAW rocket). The warhead of this weapon contains 300 g of octol, which is composed of 70/30 HMX/TNT melt cast explosive. The propellant charge is 163 g of M7 double-base propellant, containing 54.6% nitrocellulose (NC), 35.5% nitroglycerin (NG), 7.8% potassium perchlorate, 0.9 % ethyl centralite, and 1.2% carbon black (Fig. A3-3). There is

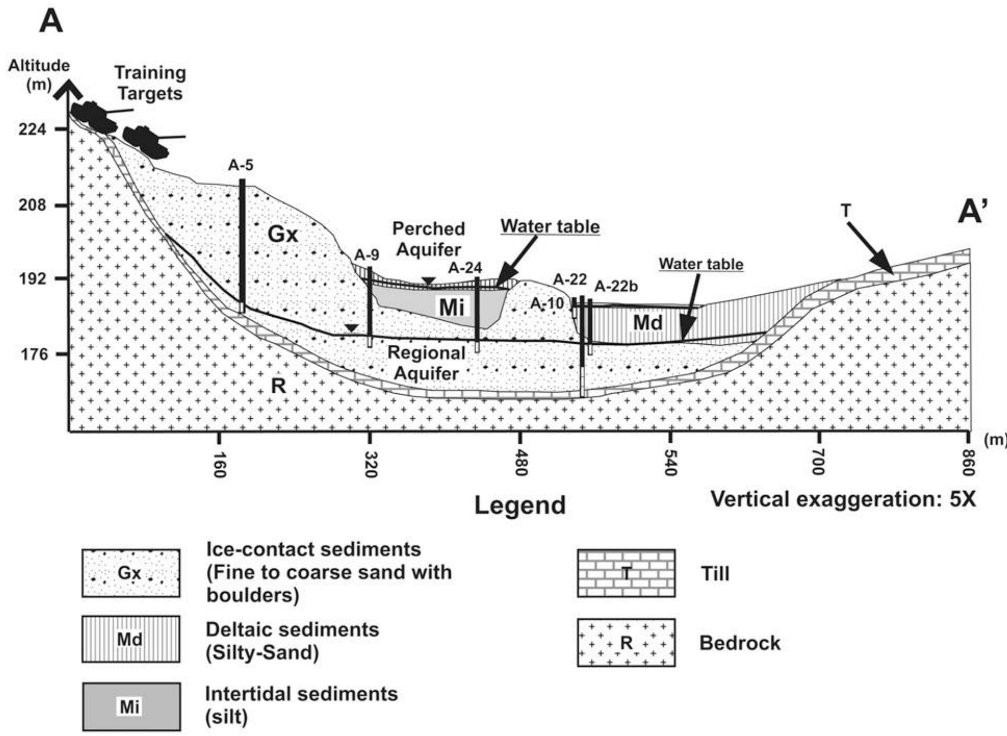

Figure A3-1. Hydrostratigraphic section along a north to south profile within the Arnhem Range area (from Martel et al. 2009).

Figure A3-2. View of Arnhem range targets from firing line position during soil sampling.

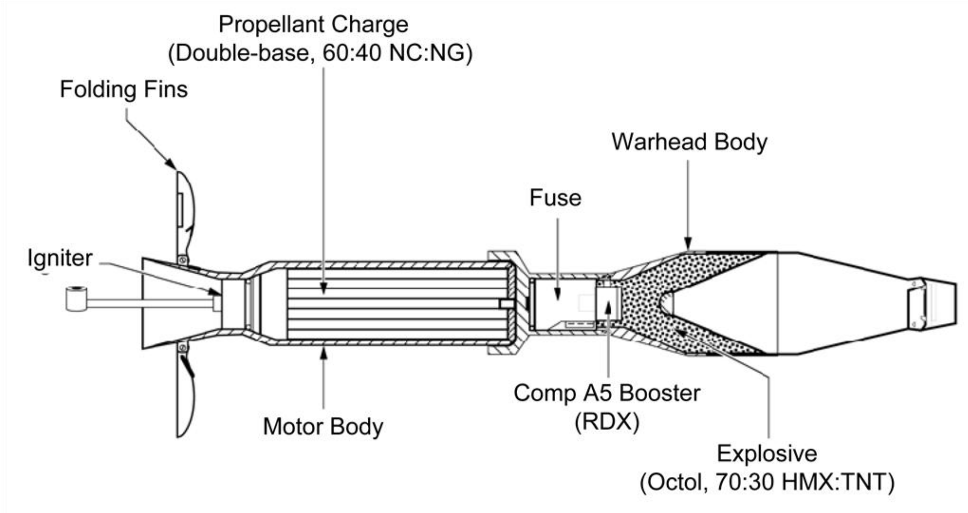

Figure A3-3. M72 Light Anti-Armor Weapon, also known as the LAW rocket.

a small amount of RDX in the booster of this weapon, and C4 block (91% RDX) has been used to detonate unexploded rockets found on the surface at Arnhem. The mass of residues of energetic compounds remaining in the impact area is due largely to ruptured M-72 rockets that did not detonate, but were ripped open by side impacts with the ground surface, spreading their undetonated explosive charge over the surface.

Soil characterization for energetic contamination

A preliminary characterization of explosives contamination in soil at Arnhem impact area was conducted in 1995 by Thiboutot et al. (1998). Analysis of these initial soil samples indicated that HMX was the major explosive contaminant present, with lesser amounts of RDX and TNT. Profile samples indicated that greater than 90% of the explosives residue was present in the top 15 cm of soil.

In 1996, a more extensive surface soil characterization was conducted in the impact area (Jenkins et al. 1997, 1999). Composite soil samples were collected within a series of grids located around one target vehicle and between it and a second target vehicle (Fig. A3-4). Once again, HMX was the predominant residue detected, with the concentrations of TNT only about 1/600th that of HMX. RDX was generally below the detection limit of about 1 mg/kg. The two mono amino transformation products of TNT (4ADNT, 2ADNT) were also detected in a number of these samples.

HMX concentrations in the surface soil (0–2.5 cm) near the targets were generally greater than several hundred mg/kg with a maximum value of 1900 mg/kg. A concentration gradient was present with concentrations dropping to less than 100 mg/kg at a distance of 20 m or so from the target. Several samples were collected from the 0–7.5 cm and 7.5–15 cm depths. For these samples the HMX concentration was about 9 times higher in the 0–7.5 cm depth interval than in the

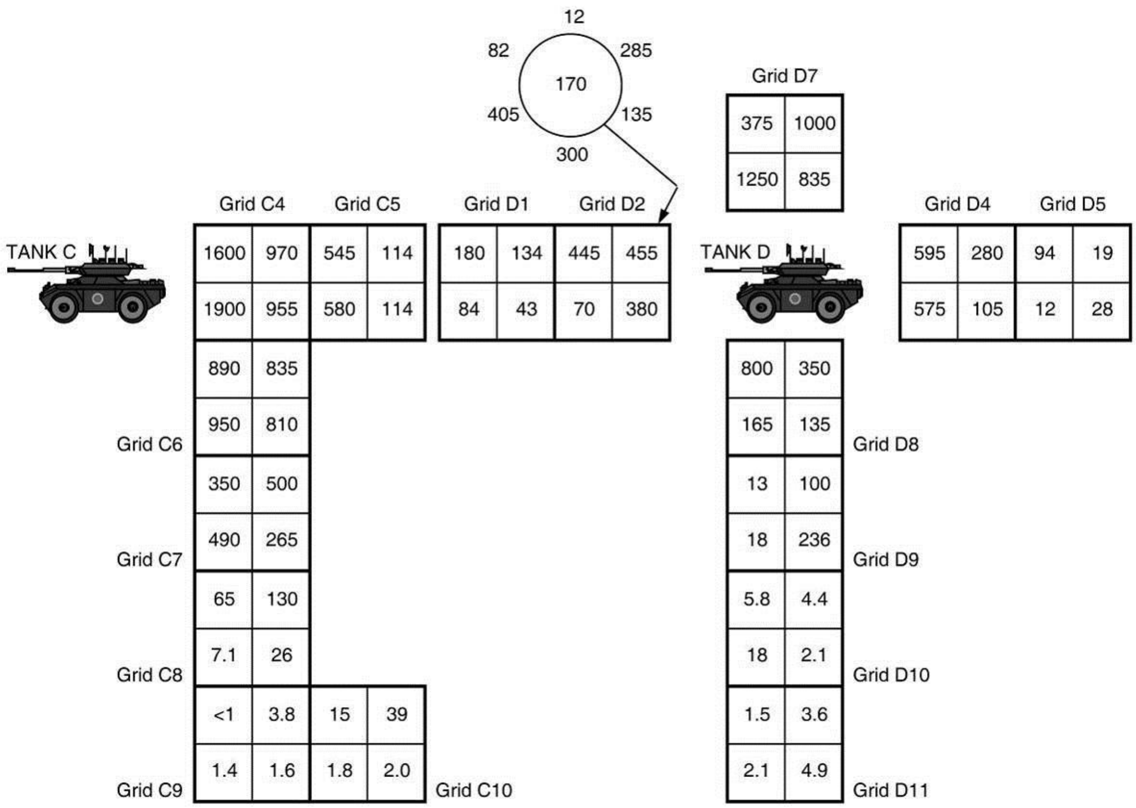

Figure A3-4.HMX concentrations (mg/kg) from commercial laboratory analysis using Method 8330. Larger grids are 6 x 6 m, subgrid size is 3 x 3 m (From Jenkins et al. 1997).

7.5–15 cm depth interval. From these results and some assumptions about unsampled areas, Martel et al. (2009) estimated the mass of HMX and TNT at the impact area to be about 16 kg and 0.1 kg, respectively. One well water sample was analyzed in 1996 and concentrations of HMX, RDX, and TNT were 295, 46 and 3.1 µg/L, respectively.

A decision was made, based on the high HMX concentrations present, its apparent mobility in groundwater, and an interest in evaluating a remediation technology, to remove the top several cm of soil from the impact area and treat it off-site to destroy the energetic residues present. This was done in 1997 using a biopile (Dubois et al. 1999). Martel et al. (2009) estimates that 85% of the HMX present at that time was removed. No characterization of the firing point area was conducted and the soil in that area of the range was not removed or treated.

After the soil removal, M-72 shoulder-fired rockets continued to be used from 1997 to 2003. In 2003, the site was again characterized for both the impact area and, for the first time, the firing point portion of the range (Jenkins et al. 2004). *MULTI-INCREMENT* samples (MIS) were taken from 10 × 10-m grids from the firing line to the center target vehicle, from segmented halos within the impact area, and from line samples along the firing line to a distance of 25 meters behind the firing line (Fig. A3-5). These MIS were collected from the 0 to 2.5 cm depth.

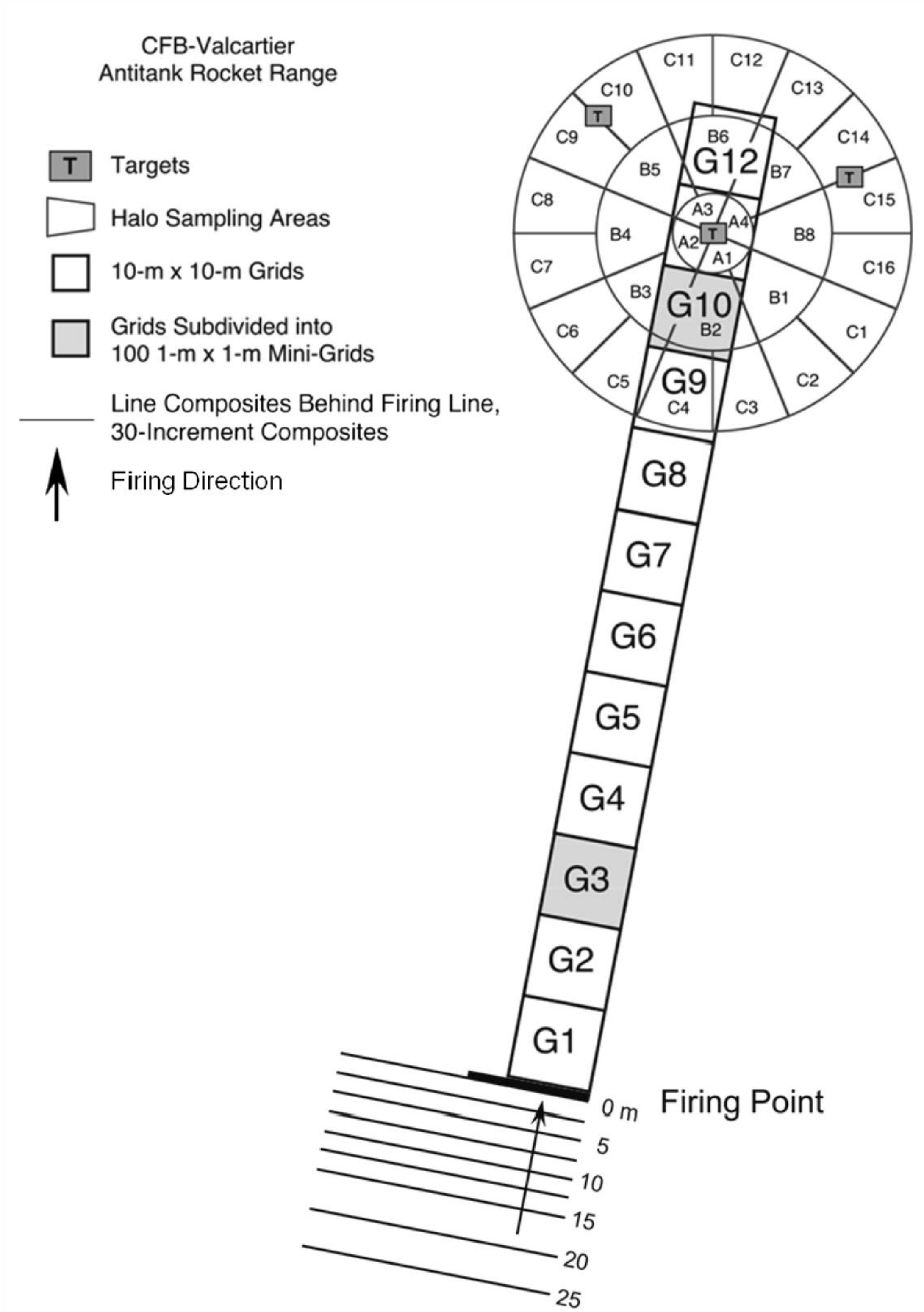

Figure A3-5. Twelve 10-m × 10-m grids located in a direct line from the firing point to and beyond the center target and halo sampling areas around target. Also shown are the positions of lines where composite samples were collected behind the firing line (Jenkins et al. 2004).

The following seven target analytes (in decreasing order of concentration) were detected in the segmented halo samples from the impact area, HMX, NG, TNT, RDX, 4ADNT, 2ADNT, and 2,4-DNT. NG had not been previously determined and it is thought to originate from residual propellant present in the motor body when the rockets detonate, or more likely rupture without detonation. Plots of the HMX and NG concentrations in the impact area in 2003 are shown in Figures A3-6 and A3-7.

Overall the TNT concentrations were only 1/84th of the HMX concentrations. A depth profile sample was collected within grid A1, near the target vehicle. Concentrations of HMX were 1030 mg/kg in the 0–2.5 cm depth interval, 17.1 mg/kg from 2.5–5.0 cm, and 1.9 mg/kg from 5–10 cm. TNT concentrations in these three depth interval samples were 0.94, 0.17, and 0.05 mg/kg, respectively. RDX concentrations were likewise 0.94, 0.06, and 1.2 mg/kg.

In two of the 10 × 10-m grids, one near the firing point (Fig. A3-5, G3) and the other near the target vehicle (G10), 100 discrete samples were also collected to characterize the short-range variability in analyte concentrations. In G3, NG was the energetic compound with the highest concentration, and individual values ranged from 0.02 to 3.37 mg/kg. In G10, HMX was the energetic compound present at highest concentration with values for discrete samples ranging

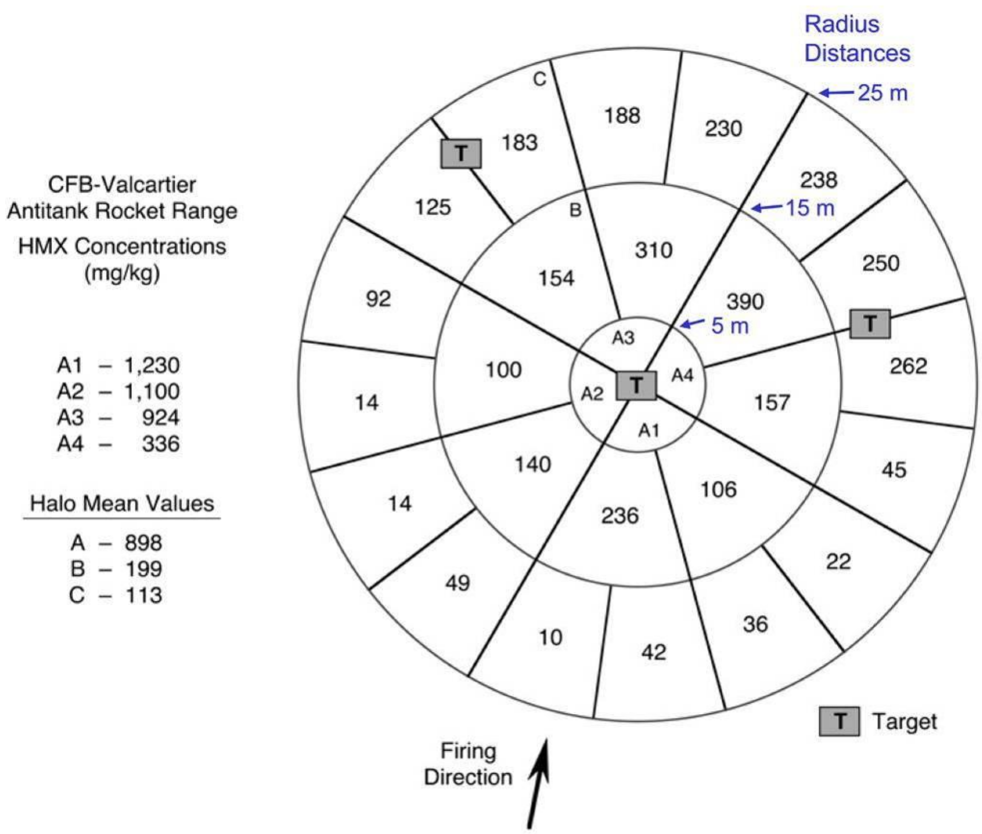

Figure A3-6. Concentration of HMX relative to sample position around targets (Jenkins et al. 2004).

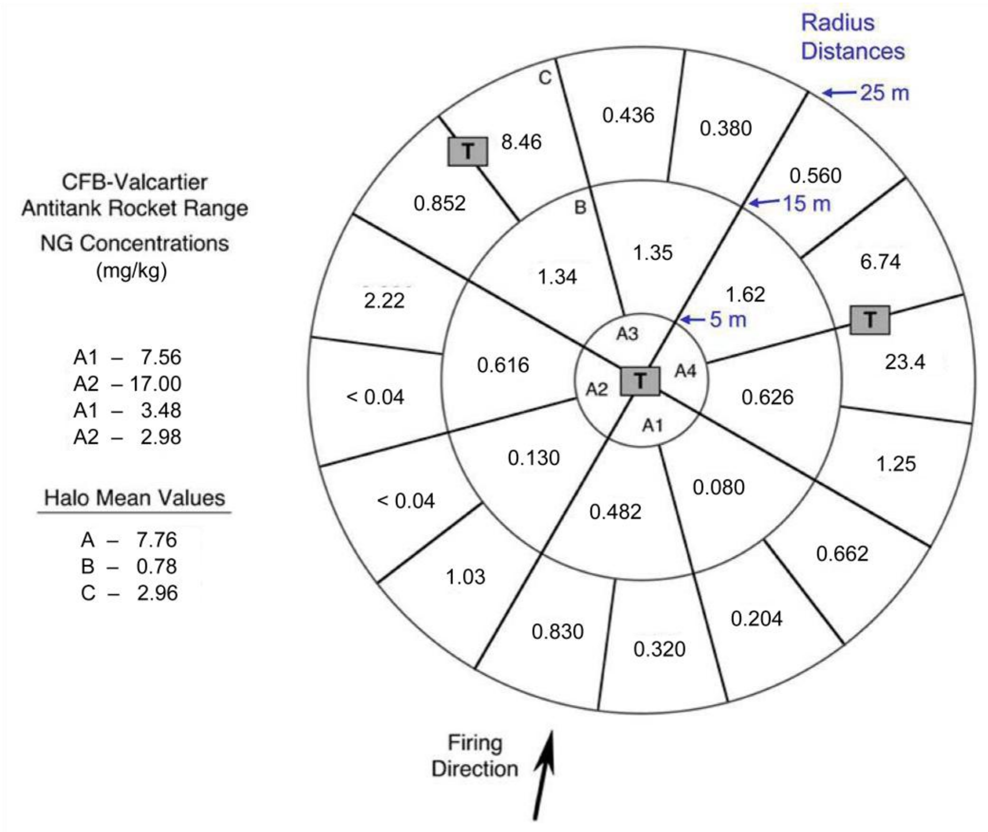

Figure A3-7. Concentration of NG relative to sample position around targets (Jenkins et al. 2004).

from 8.0 to 1920 mg/kg. These results confirm the futility of trying to estimate a mean concentration for an exposure area using a few discrete samples.

Concentrations of NG behind the firing line in the line composite samples were found to exceed those between the firing line and the target by several orders of magnitude (Fig. A3-8). The NG concentration 5 m behind the firing line was 1970 mg/kg dropping to 104 mg/kg at a distance of 25 m behind the firing line. Martel et al. (2009) estimated a mass of NG present on the Arnhem range at 63 kg in 2003.

Ground water sampling

Ground water in the regional aquifer is characterized by low electrical conductivity (about 33 µS cm-1), a high dissolved oxygen concentration (11.6 mg/L) and a pH of about 5.4. A series of ground water wells were established around the Arnhem range within the regional aquifer and were sampled in 1995, 1998, 1999, 2000, and 2005 (Table A3-1). HMX was detected in every sampling campaign; concentrations were found to be variable and related to water table fluctuations (Martel et al. 2009). A diagram of the HMX plume in 1999 is shown in Figure A3-9. In 2005, the highest HMX concentration was 92 µg/L in well A–3. Using well data and results from direct push sampling holes, Martel et al. (2009) estimated a plume length of 115 m, an average

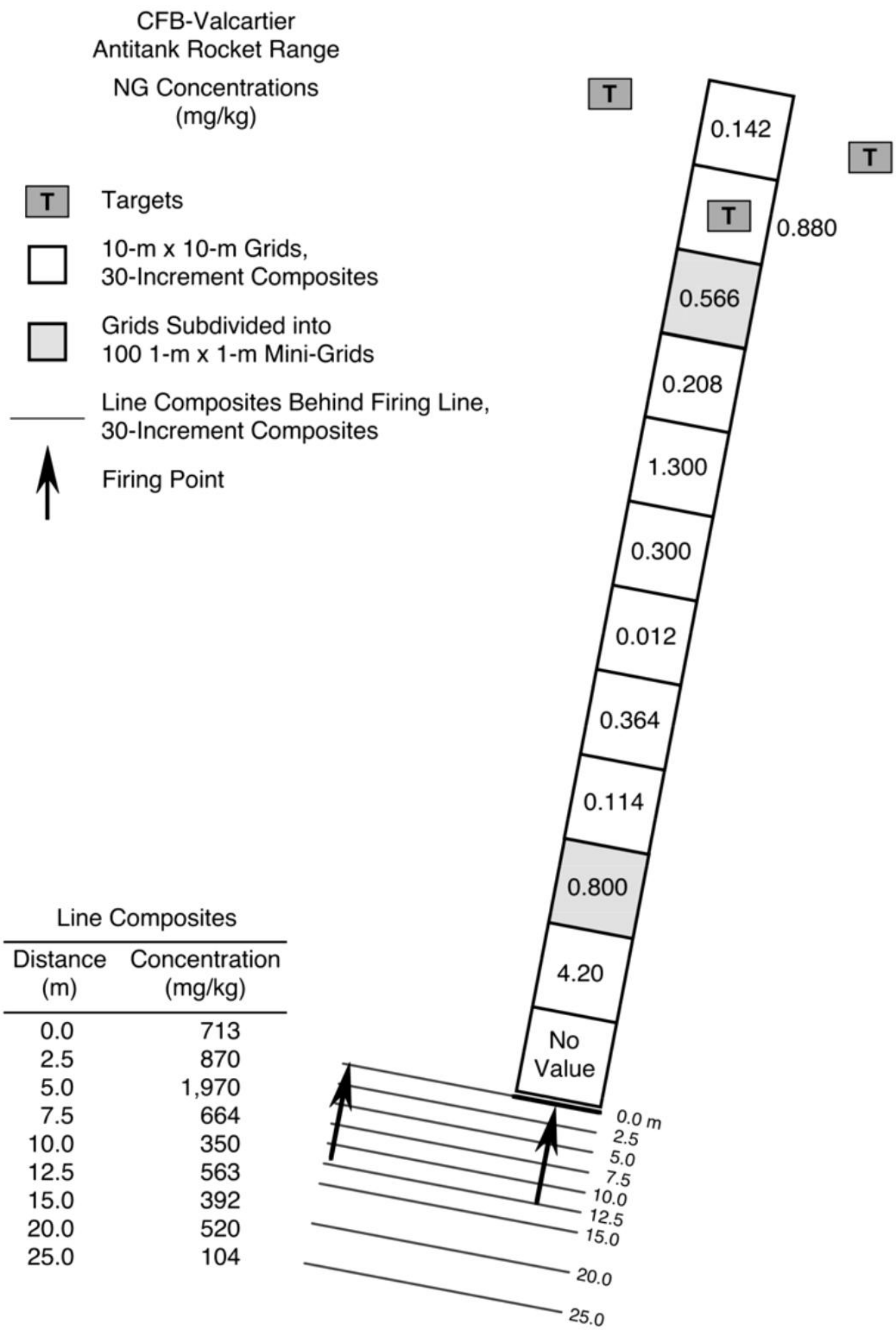

Figure A3-8. Concentration of NG in composite soil samples collected in front of and behind the rocket firing line (Jenkins et al. 2004).

Table A3-1. Concentrations of HMX in ground water (1995–2000, A-10 and P-13 in perched aquifer, others in regional aquifer). USEPA guideline for drinking water is 400 µg /L. Most well locations are shown in Figure A3-9 (From Martel et al 2009).

Date	HMX Concentration (µg/L)									
	W-1	A-3	A-4	A-5	A-7	A-9	A-17	A-18	A-19	A-25
May 1995	295	–	–	–	–	–	–	–	–	–
1 July 1998†	–	53	–	67	6	34	–	–	–	–
1 Nov. 1998	–	68	–	47	9	27	–	–	–	–
26 Mar. 1999	–	75	–	71	10.9	42	–	–	–	–
15 Apr. 1999	–	97	–	137	15	46	–	–	–	–
4 May 1999	–	125	–	114	10	32	–	–	–	–
20 May 1999	–	122	–	130	5	45	–	–	–	–
2 June 1999‡	6	56	–	116	3	17	–	–	–	–
14 June 1999§	–	–	–	–	–	–	–	–	–	–
29 June 1999	–	175	–	150	–	–	–	–	–	–
14 July 1999¶	–	–	–	–	3	–	62	21	–	–
25 Oct. 1999#	230	12	–	2.4	3	16	8	15	3	–
12 May 2000	–	140	–	113	18	40	105	39	34	–
20 Sept. 2000	175	36	7	–	<0.05	–	21	13	9	17

† 1 July 1998, <0.05 ppb: A-10, A-11, A-12, P-13.
‡ 2 June 1999, <1 ppb: A-22; <0.05 ppb: A-22B.
§ 14 June 1999, <0.05 ppb: A-11, A-12.
¶ 14 July 1999, <0.05 ppb: A-16.
# 25 Oct. 1999, <1 ppb: A-20, A-21, A-23, A-24.

aquifer thickness of 7.5 m, and an average HMX concentration of 23 µg/L. He estimated the HMX flux into groundwater to be about 3 g/day during the spring of 2005. HMX concentrations (and flux) were lower in other periods of the year, but did not drop to zero. He estimated the yearly flux to be about 0.7 to 1.0 kg, which was about 10% of the mass of HMX on the soil surface within the sand terrace, and 5% on the total range.

TNT and its transformation products (2ADNT and 4ADNT) were only detected in the ground water during sampling in 2000. The maximum TNT and 4 ADNT concentrations were 3.25 and 1.70 µg/L, respectively. TNT was not detected in 2005. In monitoring wells downgradient of the Arnhem range, RDX was detected only in fall 1998, spring 1999, and spring 2000 at a maximum concentration of 2 µg/L (Martel et al. 2009).

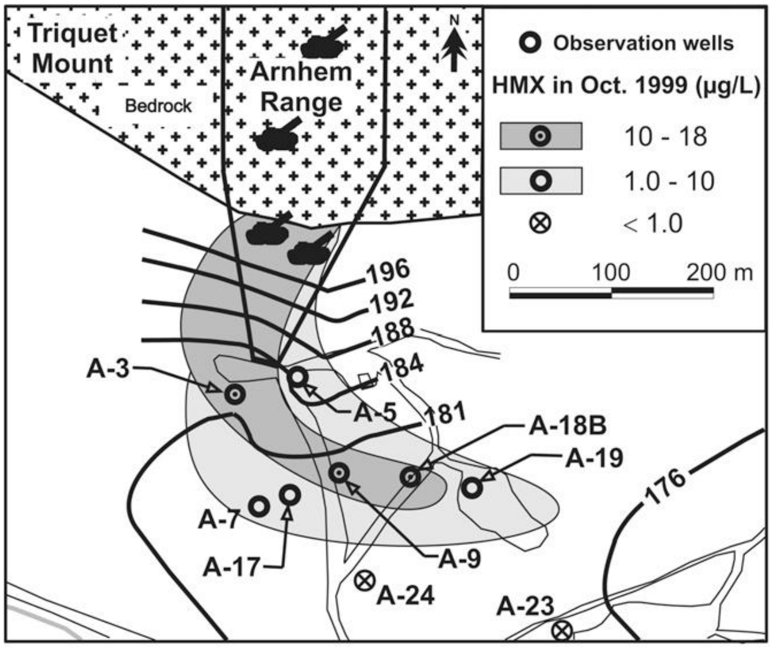

Figure A3-9. Dissolved HMX plume in ground water, fall 1999.
Wells A-20 and A-21 outside of map (<1.0 µg /L).

As noted earlier, the propellant used with the M-72 rockets at the Arnhem range contains 7.8 % potassium perchlorate. Because perchlorate is so soluble in water, and as an anion is not retained in the soil, it can penetrate deep into the soil profile and perhaps become associated with groundwater. Perchlorate was detected in groundwater at the Arnhem site (Fig. A3-10), ranging from a low of about 0.04 µg/L to as high as 14 µg/L (Martel et al. 2009). The areal distribution of perchlorate in groundwater indicated that the highest concentrations were found in the area behind the firing line, the area where most of the propellant residues were deposited.

Fate of Octol particles on the soil surfaces

Octol is a melt cast explosive with crystals of HMX dispersed in a TNT matrix. Simulated rainfall studies with Octol particles conducted by Taylor et al. (2009) indicated that TNT dissolved much faster than HMX, eventually leaving HMX crystals on the surface once the TNT was completely dissolved. This behavior is consistent with the much higher HMX concentrations found in the surface soil at the Arnhem range.

Once dissolved, the two compounds can interact with the soil. At Arnhem, the soil is very sandy and little sorption is expected. A retardation factor of between 4.5 and 6 was estimated for HMX from lysimeter studies for the Arnhem soil (Arel 2004). Soil/water partition coefficients for HMX and TNT are estimated to be within the same order of magnitude for the same soils, but these coefficients are obtained assuming that the TNT lost from solution in these equilibration tests is still intact and has sorbed onto soil. However, TNT is microbiologically (and probably abiotically) transformed under aerobic conditions in soil to 2ADNT and 4ADNT, and these two

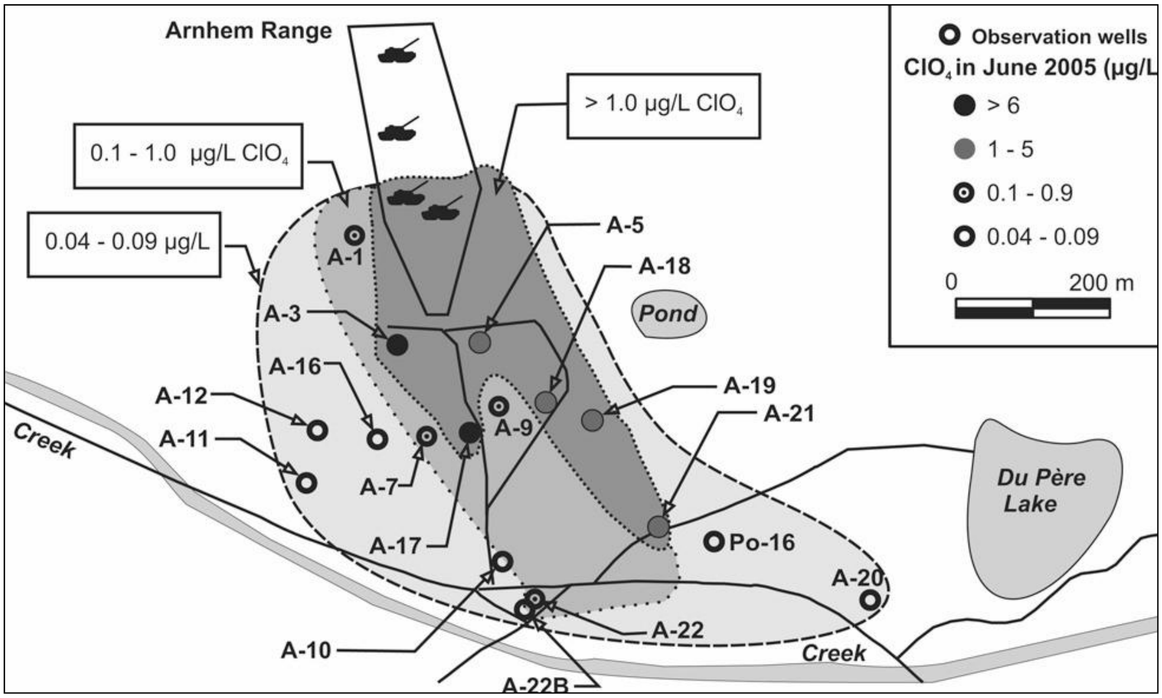

Figure A3-10. Dissolved perchlorate plume in ground water, June 2005. Wells A-11, A-12 and A-16 probably show the contribution from another perchlorate source (from the present three targets, only two have been shown). (from Martel et al. 2009).

compounds can chemisorb to organic matter present in the soil and be irreversibly bound (Thorn et al. 2002). Thus the soil water partition coefficients quoted for TNT are probably too high. HMX is not transformed under aerobic conditions and once it is dissolved, it migrates downward with percolating water. Most of the TNT is transformed into 2ADNT and 4ADNT and retained within the soil profile.

Conceptual site model

Based on the results of this study, conceptual site models for HMX and TNT behavior at the Arnhem range were developed (Fig. A3-11). Octol is deposited as particles largely from ruptured M-72 rockets. The residues are scattered onto surface soils and the distribution of Octol is very heterogeneous resulting in concentrations that vary over several orders of magnitude from spot to spot. Precipitation dissolves the octol, with the dissolution of TNT occurring at a much faster rate, leaving crystals of HMX on the surface. HMX is weakly retarded in soil and does not biodegrade under the prevailing aerobic conditions. TNT both phototransforms and, once dissolved, is biotransformed but not mineralized. TNT's transformation products can be bound irreversibly to soils and both they and TNT are only rarely observed in ground water wells located at the range. An HMX plume intercepts the regional aquifer occurs as series of slugs that are generated at each infiltration event via advective transport. The major infiltration of HMX into the aquifer occurs as a slug during spring snow melt with a smaller slug in the fall (see inset Figure A3-11).

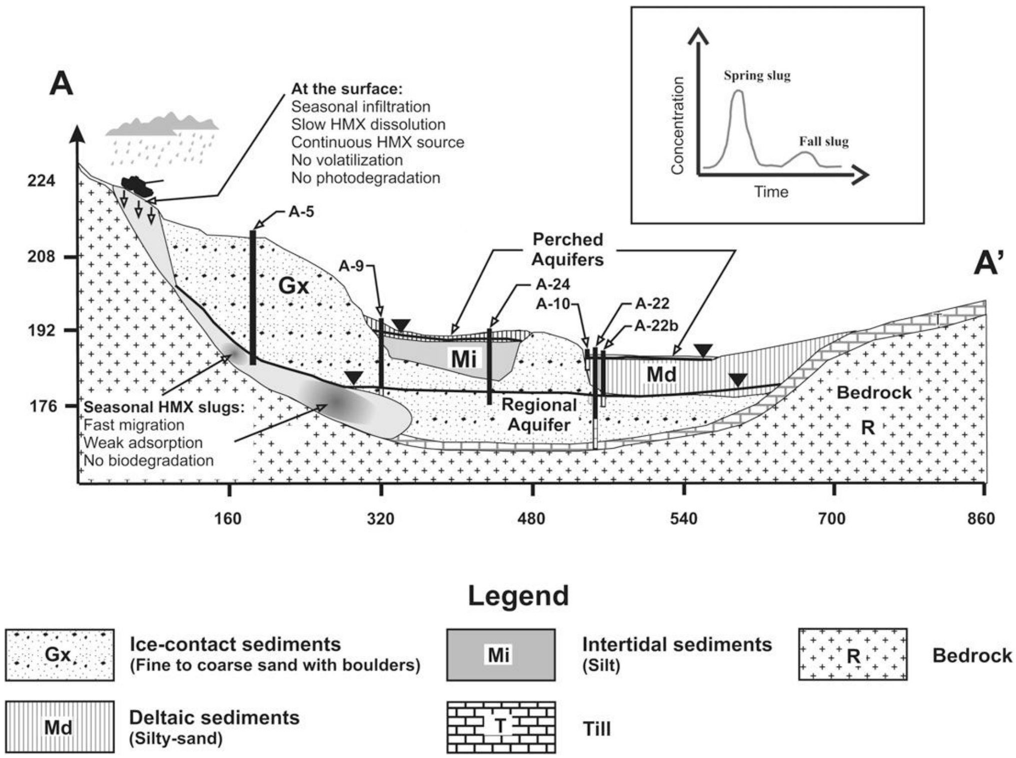

Figure A3-11. Conceptual model of HMX behavior (profile length and altitude in meters).

Conclusions

The high spatial heterogeneity of energetic compounds on the soil around targets anti-tank ranges and its implications for soil sampling has been widely described (e.g., Clausen 2005; Jenkins et al. 2004). MIS provides a reliable way for estimating the mass of EM residues at both the target and firing point portions of the range. Concentrations of energetic compounds also vary in ground water at the Arnhem Anti-Tank Range where concentrations vary in time and space.

This work demonstrates that the flow regime has to be well known when characterizing the ground water contamination related to an anti-tank training range and probably other types of ranges as well. In the case of variable water levels and substantial parts of the aquifer below the training area changing between saturated and unsaturated conditions, sampling periods have to be chosen with great care because observed ground water contamination may vary with the seasons. High infiltration rates cause higher mobility of energetic compounds but may also dilute the concentrations. Snow cover and frozen ground inhibit infiltration for several months, causing an accumulation of contaminants at the ground surface, which may be leached just after snowmelt, causing an extreme peak in the concentration of energetic compounds in groundwater.

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Appendix A4. Case Study: Estimating perchlorate deposition from the firing of a MLRS rocket.

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Introduction

Ammonium and potassium perchlorate are present in a variety of US military items including large rocket motors such as the Multiple Launch Rocket System (MLRS). A study was conducted to assess the deposition of ammonium perchlorate near where this rocket system was fired. The propellant for the MLRS rocket is 98.2 kg (216.5 lb) of Arcadene 360B with 630 g of WC818. The Arcadene 360B is composed of ammonium perchlorate, aluminum powder, HTPB, dioctyl adipate, iron oxide, and less than a percent of several other non-energetic compounds. The rocket motor contains 67.8 kg of ammonium perchlorate or 57.4 kg of perchlorate. WC818 is composed of mostly NC, with smaller amounts of NG, dibutylphthalate, calcium carbonate, and less than a percent of several other non-energetic compounds.

Under normal firing conditions, the residue would be deposited over a very large area as the rocket ascends. In this study, the rocket propelled a sled along a rail that is approximately 1 m above the ground, and residues are deposited over a much smaller surface area near the sled track.

Methods

A diagram of the sampling design at the sled track is shown in Figure A4-1. Forty-six surface soil samples were collected up to 50 m behind the firing line and along the first 274 m (900 ft) of the sled track. Along the track, samples were collected on both sides of the track in 45.6-m (150-ft) intervals, at a distance of 0 to 10 m from the edge of the track. Half of the samples were collected the day prior to firing the MLRS rocket and the other half were collected within three hours after the MLRS rocket was fired. At this facility, the rocket sled is propelled along the 610-m (2000-ft) sled track. Based on information provided by the test site engineer, the rocket motor was operational along the entire portion of the track that was sampled. No rain occurred throughout the two days we sampled.

Multi-increment soil samples were collected behind the firing point and along a sled track before and after launching a single Multiple Launch Rocket System (MLRS) rocket. In all cases, surface soil samples were collected with either a 3-cm-diameter corer (M.R. Walsh 2004) or a stainless-steel scoop. The choice of which tool to use depended on the hardness of the surface

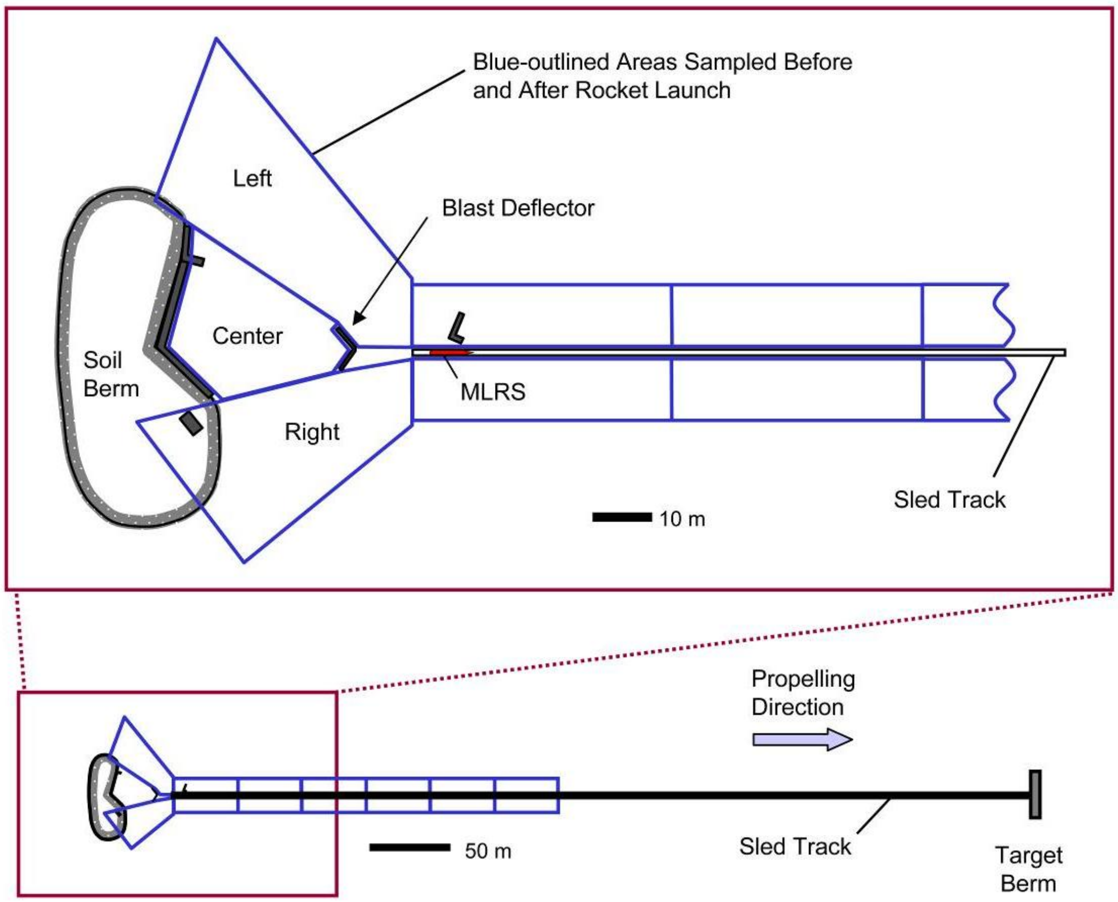

Figure A4-1. Diagram of sled track including sampling areas for multi-increment soil samples.

and the cohesiveness of the soil. In all cases, we collected multi-increment surface soil samples 0 to 2.5 cm below the surface; the number of increments per sample ranged from 38 to 82. In some cases, however, we could not push the sampler a full 2.5 cm into the hard-packed soil; those increments were from shallower depths.

All soil samples were returned to the laboratory by overnight carrier. Soil samples from this test were dry and were processed without further air-drying. Sample weights varied from 1320 to 3801 g. Each sample was passed through a 10-mesh (2-mm) sieve to remove oversized material. The entire fraction of the sample that was less than 2 mm was ground in portions that did not exceed 600 g using a Lab TechEssa LM2 (LabTech Essa Pty. Ltd., Bassendean, WA, Australia) puck-mill grinder. Each portion was ground five times for 60 seconds, reducing the particle size of the material to a flour-like consistency (< 70 µm). After all the portions for a given sample were ground, the portions were combined and mixed thoroughly, and spread out on a tray to form a 1-cm-thick layer. Subsamples were obtained by collecting 30 increments randomly from the entire thickness of the pulverized material.

A 10.0-g portion of each soil was extracted with 100 mL of reagent-grade water from a Milli Q, reagent-grade water system (Millipore Corp.) for 18 hours on a platform shaker. All aqueous extracts were passed through a 0.45-µm Millex-HV filter unit (Millipore Corp.) and perchlorate was determined with ion chromatography using suppressed conductivity detection according to the general procedures outlined in EPA Method 314.0 (US EPA 1999). The analytical detection limit for Method 314.0 was 10 µg/kg. Because none of the samples were determined to have perchlorate concentration above this value, portions of a few soil samples were sent for analysis by Method 314.0 analysis using equipment with a lower detection limit (1.0 µg/kg). An additional subset of samples was sent to a commercial laboratory for LC/ESI/MS (Liquid Chromatography Electrospray Ionization Mass Spectrometry) according to Method 331.0 (US EPA 2005).

Results and Discussion

Results of analysis of soil samples collected before and after the rocket was fired are presented in Table A4-1. We suspected that the largest mass of propellant would be deposited behind the firing position, as had been found for smaller, shoulder-fired rockets (Jenkins et al. 2004). For that reason, we collected triplicate field samples on the left and right side of the deflector structure behind the firing point (Fig. A4-1). The mean concentrations in soil on the left side of the deflector before and after the firing of the MLRS were 6.0 and 5.9 µg/kg, respectively. Similarly, the mean concentrations on the right side of the deflector were < 1.0 and 2.3 µg/kg, respectively. In neither case was the soil concentration after firing significantly different from the concentration before firing at the 95% confidence level. The perchlorate concentrations before and after the rocket firing in the center behind the deflector were < 1.0 and 1.3 µg/kg, respectively.

Soil samples were also collected along the sled track at distances from 0 to 274 m ahead of the firing point both before and after the rocket fired (Table A4-1). Eighteen samples were analyzed from those collected. The mean concentration for the nine samples collected before the firing was <1.0 µg/kg and the mean concentration for the nine samples collected after the firing was also < 1.0 µg/kg. Thus, we were not able to detect a significant increase in the perchlorate concentration either behind the firing line or along the sled track after a single MLRS rocket was fired.

Even though the amount of perchlorate deposited from this rocket was too low to measure, we can estimate the mass of perchlorate that would have had to be deposited for us to measure a significant increase in concentration. We made this estimate by calculating the surface area from which soil samples were collected, multiplying by the 2.5-cm depth sampled to compute the volume of soil in this zone, and multiplying by an estimate of the bulk density of soil (1.7 g/cm^3). The total mass of soil was estimated at 3.31×10^5 kg. Because the total area of deposition is probably greater than the area we sampled, we multiplied this mass by 2. If deposition from the

Table A4-1. Concentration of perchlorate in surface soils (0–2.5 cm) at Eglin AFB sled track before and after MLRS rocket firing. Samples consist of 38 to 60 increments.

Location				Perchlorate Concentration (µg/kg)				
				Before		After		
Position	Side	Distance		CRREL*	EL†/Other	CREL†	EL†/Other	Difference
Behind	Left	0–46 m	Rep 1	< 10	6.3†	< 10	6.8†	
			Rep 2	< 10	5.9	< 10	4.9	
			Rep 3	< 10	5.7	< 10	5.9	
		mean		< 10	6.0	< 10	5.9	–0.1
	Center	0–46 m		< 10	< 1.0†	< 10	1.3†	> 0.3
	Right	0–46 m	Rep 1	< 10	1.0	< 10	1.0	
			Rep 2	< 10	< 1.0	< 10	1.5	
			Rep 3	< 10	< 1.0†	< 10	4.3†	
		mean		< 10	< 1.0	< 10	2.3	> 1.3
Ahead	Right	0–46 m	Rep 1	< 10	< 1.0	< 10	< 1.0	
			Rep 2	< 10	< 1.0	< 10	< 1.0	
		mean		< 10	< 1.0	< 10	< 1.0	ND
	Left	0–46 m	Rep 1	< 10	1.1	< 10	< 1.0	
			Rep 2	< 10	< 1.0	< 10	< 1.0	
		mean		< 10	< 1.0	< 10	< 1.0	ND
	Right	46–92 m		< 10	< 1.0	< 10	< 1.0	ND
	Left	92–137 m		< 10	1.4	< 10	3.5	2.1
	Right	137–183 m		< 10	< 1.0	< 10	< 1.0	ND
	Left	183–229 m		< 10	< 1.0	< 10	1.2	> 0.2
	Right	229–274 m		< 10	< 1.0	< 10	< 0.1	ND

* Ion chromatography method.

† Data from EL-Omaha - Ion chromatography; other results from contractor laboratory - LC/EIS/MS method.

rocket raised the perchlorate concentration in the soil within this zone by 1 µg/kg, the mass deposited would be 662 mg. Pooling the standard deviations of the data sets that had three measured values above the analytical reporting limit before or after the rocket was fired, we can estimate an average total measurement uncertainty of 1.2 µg/kg. Thus, to measure a significant concentration increase at the 95% confidence level, the soil concentration would have to be raised by 2.4 µg/kg. Thus, the amount of perchlorate deposition would have to have been at least 1.6 g to be detected. Because we were unable to detect a significant increase in concentration in this experiment at the 95% confidence level, we can assume the deposition of perchlorate was less than 1.6 g. Because the rocket initially contains 57.4 kg of perchlorate, at least 99.997% of the perchlorate is destroyed during firing. Thiboutot et al. (Chapter 6 in Jenkins et al. 2007) estimated that only 2 mg was deposited when an Mk58 rocket motor that contains 47 kg of ammonium perchlorate was fired. Our findings are consistent with their estimate; however, our values are more uncertain because we were not able to measure any significant perchlorate deposition.

Overall, the firing of one MLRS rocket did not increase the perchlorate concentration in the soil at the sled track above background levels. The efficient burning of the rocket motor appears to destroy at least 99.997% of the perchlorate in the motor. This result is consistent with that found by the Canadians for the AIM-7 missile test (Chapter 6 in Jenkins et al. 2007). Oxley et al. (2009) found that perchlorate residues of about 0.0022 % remained compared to the initial perchlorate present in the rocket formulation. They concluded that "the large quantities of perchlorate in propellants are effectively destroyed during the burning process leaving minimal perchlorate residue."

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Appendix A5. Case Study: Site Inspection at the Former Farragut Naval Training Center/ Idaho Department of Fish and Game Farragut Firing Range Athol, Kootenai County, Idaho

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SUSAN BIGL, SUSAN TAYLOR; USA ERDC/CRREL

The following is a summary of a site inspection conducted by EPA Region 10 at the Idaho Department of Fish and Game Farragut Firing Range (Farragut) in Athol, Idaho (Techlaw 2010). Multi-increment samples were collected to determine average concentrations of both metals and energetic compounds at a portion of this small arms training facility.

Site History and Description

Farragut served as a Naval training station from 1942 to 1944 and was decommissioned in June 1946. In 1950, the DoD conveyed the site to Idaho Fish and Game and the site is currently used by the Idaho Department of Parks and Recreation as a public firing range (Helmich et al. 1999, Leptich et al. 2005).

The Farragut site is approximately 1000 ft long by 600 ft deep. The western half remains unchanged since the Navy built it during World War II and is the area studied during this site inspection (Figure A5–1). The southern 520-ft wide shooting bay is directed towards eight targets at the northern portion. The range floor, the area between the firing line shelter and the targets, is overgrown with vegetation. Just to its north is an 8-ft deep concrete pit extending the length of the range, behind which is an impact berm approximately 30 to 40 ft higher than the top of the pit. Beyond the impact berm is forested acreage. Samplers observed shooting debris scattered throughout the bay during their 2008 site reconnaissance and 2009 SI sampling event.

Potential Contaminants of Concern

The purpose of the SI was to measure the concentrations of metals in the soils. Lead is deposited at firing ranges as lead shot and bullets, most of which are in the berm soils. Since lead oxidizes when exposed to air and dissolves when exposed to acidic water or soil; it has the potential to migrate through soils to groundwater. Other chemicals of concern at small arms ranges include arsenic and antimony (from ammunition), nickel (coating on some lead shot), copper, zinc, strontium, and magnesium (from tracer rounds used in machine guns), and polycyclic aromatic hydrocarbons (from clay targets and ‘wadding’ from shotgun shells) (US EPA 2003). Nitroglycerin and 2,4-Dinitrotoluene are commonly used in propellants and were analyzed for in the firing point and background samples.

Figure A5–1. Air photograph of the Farragut firing range with overlays showing the boundaries of the sampling units. Inset shows the general location of Farragut. (after Techlaw 2010).

Sampling Methodology

The range was divided into seven sampling units, two at the firing line, three within the range floor, and two on the target berm (Fig. A5–1). A total of nine multi-increment samples were collected: one from each sampling unit, one background sample, and one duplicate from the near range floor (Techlaw 2010). The Range Floor samples were built from 60 increments; all others had 30 increments (Table A5–1). The background sample was collected from an area similar in size to the firing point, with a similar substrate, and approximately 0.3 mi up-gradient of the Farragut site.

A die was rolled to randomly select the starting point in the northwestern corner of each sampling unit and MIS samples were collected on an even spacing from there (Fig. A5–2). The sampling team used a handheld Garmin ETrex GPS unit to record GPS coordinates of all sample locations. Samples were collected first from sampling units thought to be the least contaminated and then from those expected to be most contaminated. Increments from the firing line, range floor, and the background location were collected 0 to 2 inches below the surface. Increments collected in the Berm and Target Areas were collected from 0 to 12 inches from the surface, assuming that bullets would penetrate more deeply into the berm. All of the samples were obtained below the vegetative cover. After collection, the combined soil increments were sieved with a number 14 USA standard testing sieve. The single homogenized MIS sample was then transferred to a 32-oz high-density polyethylene (HDPE) container.

Table A5–1. Sampling units evaluated.

Unit	Sampling Unit Description	Increments
1	Historical Firing Pt.	30
2	Historical and Current Firing Pt.	30
3	Near Firing Pt. Range Floor/Fall Zone	60
4	Middle Range Floor/Fall Zone	60
5	Near Berm Range Floor/Fall Zone	60
6	Front Face Berm	30
7	Middle Berm	30
8	Background Sample	30

Analysis

All samples were analyzed for target analyte list (TAL) metals; the two firing point samples and the background sample were also analyzed for explosives and propellant compounds (Techlaw 2010). Both types of analysis were conducted by the EPA's Manchester Environmental Laboratory. The metals analysis followed EPA Method 200.7/200.8. Explosives and propellant residues were measured by high performance liquid chromatography (HPLC) using a dual wavelength ultra violet (UV) detector using EPA Method 8330B.

Specifics regarding QA/QC performed are described by Techlaw (2010). Concentrations considered significantly above background were defined in the SI plan, via a consensus based approach, as those that were at least three times greater than the background concentration when the background concentration equaled or exceeded the detection limit.

Results

Analyses of the background sample detected all 13 analyte metals but no energetic compounds (Table A5-2). The range samples had elevated concentrations of lead, copper and antimony with the highest concentrations in the berm soils and decreasing concentrations towards the firing point. The berm face was also found to have elevated cadmium; arsenic was found at the active firing point, on the range floor and in the berm face. Of the suite of targeted energetics compounds (17 analytes in Method 8330B) only nitroglycerin and 2,4-DNT were detected in the firing point sampling units. This result is expected as these two compounds are used in propellants whereas other energetic compounds, such as TNT and RDX, are not.

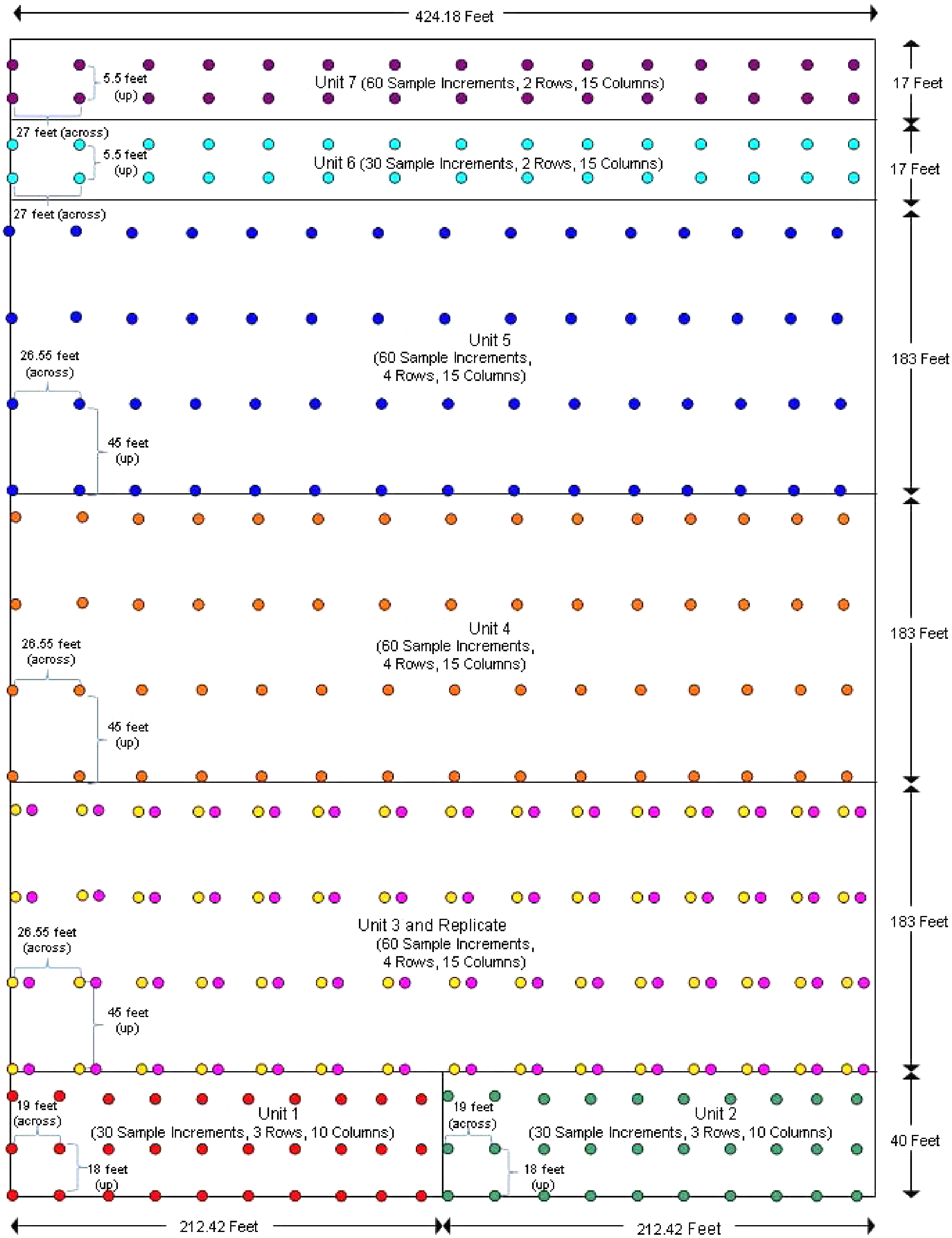

Figure A5–2. Schematic of sample increment locations at Farragut Firing Range.

Table A5–2. Concentrations of metal and energetic compounds in Farragut Range MIS Samples. Values underlined and in bold are over three times higher than the background concentrations.

Location	Firing Point		Range Floor				Berm		Background
	Historical	Both	Near Firing Point		Center	Near Berm	Face	Middle	
TAL Metals (mg/kg)			*Rep 1*	*Rep 2*					
Antimony	--	--	**31.0**	**27**	**220**	**24.0**	**400**	**180**	< 4.6
Arsenic	18	**30.9**	17	17	**24.3**	16	**23.8**	23.1	7.8
Barium	201	186	255	245	204	100	97.9	150	291
Beryllium	0.63	0.685	0.67	0.706	0.598	0.502	0.561	0.726	0.678
Cadmium	--	0.64	--	--	--	--	**2.01**	--	0.54
Chromium	10.4	15.1	9.29	9.7	10.5	14.5	13.1	14.1	8.48
Cobalt	8.0	11.8	5.74	5.92	6.09	6.79	6.59	7.67	5.13
Copper	**46**	**69**	**57**	**52**	**330**	**100**	**1200**	**940**	14
Lead	**67.2**	**202**	**1,510**	**1,670**	**7,130**	**2,470**	**24,100**	**21,800**	20.5
Manganese	716	652	715	707	703	507	555	645	1,100
Nickel	12.7	18.2	10.2	10.3	11.0	11.3	12.9	14.7	9.9
Thallium	10	11	14	14	12	11	11	14	14
Vanadium	17.8	21.2	22.5	23.6	21.0	24.1	20.7	26	22.8
Zinc	74.1	79	75.7	76.9	99.8	68.1	193	175	69.4
Nitroaromatics, Nitramines, and Nitrate Esters (mg/kg)									
DNT	**0.83**	**4.2**	--	--	--	--	--	--	--
Nitroglycerin	**29**	**170**	--	--	--	--	--	--	--

TechLaw collected a duplicate multi-increment sample from the Range Floor nearest the firing points to estimate the overall error from collecting, processing, sub-sampling and analyzing these samples. Comparison of the concentrations obtained from these two multi-increment samples show excellent agreement indicating that multi-increment samples worked well for estimating the concentrations of metals in these soils.

Lastly, the Manchester Environmental Laboratory estimated both the carryover from one sample to the next and the metals introduced by the grinding process when metallic grinding equipment was used. Ottawa Sand was processed using the same equipment used to pulverize the range samples. Table A5–3 shows the elemental concentration of Ottawa sand compared to Ottawa sand ground after a highly contaminated sample and after a background sample. Also listed is the metal composition of the metal grinding bowl. The results show increases in the concentrations of chromium, copper, manganese, and lead in the Ottawa sand. For lead, grinding introduced ~ 4.7 mg/kg into the sand, about one quarter the background level of 20.5 mg/kg and a value order of magnitude lower than any of the lead concentrations in the samples. Although these additions could be significant for trace metal work, they are unlikely to be important for contaminated range soils.

Table A5–3. Metals in Ottawa Sand.

Metal Analyte	Concentration (mg/kg)			
	Ottawa Sand			In Steel Bowl
	Unground	Ground		
		After Sample	*After Background*	
Al	20.8	57.2	58.5	
Ca	201	215	227	
Fe	1,550	9,800	7,550	> 95%
K	53	67	76	
Mg	132	55.1	61	
Na	7.6	23	19	
Ba	ND† (<0.15)	1.41	1.27	
Co	0.39	0.77	0.68	2.0
Cr	ND (<.76)	3.1	2.1	2.5
Cu	1.7	5.08	4.32	5.0
Mn	1.36	82.5	56.9	20.0
Ni	1.4	3.1	2.7	5.0
Pb	ND (<2.3)	4.7	ND (<3.3)	2.0
Zn	ND (<.38)	0.50	ND (<0.54)	2.0

† Not Detected

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Appendix B. Fundamental Error

It is important when considering sampling/subsampling efforts to characterize the concentrations of munition constituents in soil to understand that these residues have been largely heterogeneously deposited in source regions as particles of various sizes. Whether this is from low order detonations at impact areas or propellant residues at firing points, these residues remain as particles until they are dissolved or leached by precipitation. Thus soils in theses source zones contain the normal array of mineral and organic substrates commonly encountered in soil as well as particles of the energetic compounds with a wide variety of particles sizes randomly distributed throughout.

It is difficult to collect representative soil samples to estimate target analyte concentrations when the analytes of interest are present in particulate form and distributed in an extremely heterogeneous fashion. It can be just as difficult to obtain a representative subsample from a bulk sample under these conditions. But it must remembered that only a small portion of the total soil from a site is actually extracted to estimate analyte concentrations. Thus, it is critical the portion actually chosen for extraction and determination is representative of the soil sample collected and of the sampling unit.

Heterogeneity exists at two scales with the first due to unequal deposition of residues within the area sampled, which is referred to as "distributional heterogeneity." On a smaller scale, the particles of residue vary in size (and thus mass and concentration), as do those of the soil matrix itself. Collecting a soil sample that adequately represents all the particles sizes of both residue and soil matrix is very difficult, and the difficulty increases as the sample size decreases. This form of heterogeneity is called "compositional heterogeneity."

It is very important to consider compositional heterogeneity when selecting an adequate subsampling protocol for soil samples containing energetic residues. Because only a portion of the total sample will be used for extraction and analysis, a subsampling error is introduced, which is a function of the ratio of the subsample mass to that of the bulk sample. Clearly it is more difficult to adequately represent all the particles sizes present as the total mass of the subsample is reduced. Also, the magnitude of the subsampling error increases as the particle sizes of the energetic residue increases. This leads to the concept of "fundamental error (FE)." FE, in this case, is the error in representing the bulk sample due to the inability to adequately represent the bulk sample's particles size distribution within a subsample of a given mass. It can be thought of as the unavoidable error when subsampling a particulate population and it can be estimated using sampling theory as devised by Pierre Guy (Pitard 1993). The FE error is the minimum subsampling error that remains when all other subsampling operations are perfect. It can only be decreased, by increasing the mass of the subsample, or by reducing the particles sizes of the residue and matrix.

This Appendix addresses FE, the most important statistical parameter to understand when sampling soil containing particulates. This error is fundamental to the composition of the particles (or other items or fractions) of the lot being chemically or physically different: that is, it is a result of the compositional heterogeneity (CH) of the lot. In this definition of FE, the lot is also known as the population, sampling unit, sampling area, or area of concern. Thus, this is the only sampling error that can never be eliminated. To obtain an accurate representation of CH, one must be sure the samples are always representative of all the particle size fractions present. The relative variance of the FE (s^2_{FE}) can be estimated before sample selection and may be reduced by decreasing the diameter of the largest particles to be represented or by increasing the mass of the sample (U.S. EPA 2003).

Fundamental error and the incremental sampling theory were developed by Pierre Gy to obtain representative soil samples containing minerals from heterogeneous media (Pitard 1993). The study of sampling of particulate materials starting in the 1950's and culminated in Gy's final theory in the 1980's and 1990's. Initially this theory was developed for the mining industry to estimate the value of mineral deposits. The sampling strategy described in this document was refined to address MC, by adapting Gy's principles to address the major confounding factors for obtaining project suitable environmental data. To representatively estimate the concentration of a given constituent in an area where there has been a release into the environment, the sampling strategy and sample processing protocol must address the compositional and distributional heterogeneity, to the degree necessary to meet the DQOs (Ramsey and Hewitt 2005).

Compositional heterogeneity results from the fact that individual particles within a population often have different concentrations of target analytes. This heterogeneity is at a maximum when some of the target analytes are present as discrete particles. Error due to compositional heterogeneity is called the FE and is inversely related to the sample mass. Distributional heterogeneity is due to uneven scattering or release of COPC across the site, sometimes with a systematic component as well as a short-range random component. Error resulting from distributional heterogeneity is inversely related to the number of increments used to build the sample. This error is at a maximum when a single discrete sample is used to estimate the mean for a large sampling area.

The recognition of this approach for the collection and processing of environmental samples was enhanced by its documentation in Method 8330B (US EPA 2006). To reduce the influence of these error sources when estimating the mean concentration of an analyte within a sampling area, Method 8330B recommended the collection of 30 or more evenly spaced increments to build a sample with a total sample mass >1 kg (Jenkins et al. 2004a, 2004b, 2005, 2006, 2008;

M.E. Walsh et al. 2005; Hewitt et al. 2007). The objective of this sampling technique is to obtain a representative amount of every particle size and composition within the lot. In the case of residues of energetic compounds this would include small (< 2mm) pieces of high explosive materials (e.g., TNT, Composition B, Tritonal, etc.), propellants, and rocket fuels, of a variety of configurations (e.g., crystalline spheres, elongated fibers, etc.). Of equal importance, the sampling design should not over-sample or miss any portion of the sampling area.

The field or laboratory, or both, processing protocols must also address the compositional and distributional heterogeneity to ensure that subsamples are representative of the field sample to the degree specified in the DQOs. That is, the entire field sample must be handled and processed in a manner that allows a sample split or any given subsample aliquot, to accurately represent the original bulk sample. Table B-1, found at the end of this Appendix, is an example of how accuracy can be demonstrated for energetic residues in a field sample. In the case of residues of energetic compounds, Method 8330B recommends the entire field sample be air dried and then passed through a #10 (2-mm) sieve. This step also provides a safety feature, since energetic materials >2 mm are excluded from grinding. Thus, splitting the sample in the field is not recommended, even if the sample can be air-dried and sieved. Once sieved, the <2 mm fraction of the sample is then mechanically pulverized to reduce the particle size of both the matrix and constituents of concern to <0.075 mm. Pulverization was deemed necessary since energetic residue particles <2 mm exist as a variety of sizes, shapes and compositions. That is, even after air-drying and sieving, the compositional heterogeneity is too great within the <2 mm fraction to ensure that subsamples or sample splits would retain representative portions of energetic residues (M.E. Walsh et al. 2002; Hewitt et al. 2007, 2009). To further reduce the uncertainty among subsamples, Method 8330B recommends a 10-g subsample size be obtained by combining many (≥ 30) smaller increments.

According to Pierre Gy's theory to assess the overall sampling error (OE) one must sum the total sampling error (TE) and the analytical error (AE). Equation 1 allows an estimation of the overall measurement quality by evaluating error at all stages; including the representativeness of the sample and whether the same types of particles are in the same proportions as the population.

$$1\} \qquad OE = TE + AE$$

where:
OE = overall sampling error,
TE = total sampling error, and
AE = analytical error.

Total sampling error can be further refined into the total sampling error occurring in the field (TE_F) and the total sampling error occurring in the laboratory (TE_L). Thus,

$$2\} \qquad OE = TE_F + TE_L + AE$$

where:
OE = overall sampling error,
TE_F = total sampling error occurring in the field, and
TE_L = total sampling error occurring in the laboratory.

Pierre Gy's theory also recognizes seven basic sampling (TE) errors:

1. Fundamental Error (FE)
2. Grouping and segregation Error (GE)
3. Long-range Heterogeneity Fluctuation Error (CE_2)
4. Periodic Heterogeneity Fluctuation Error (CE_3)
5. Increment Delimitation Error (DE)
6. Increment Extraction Error (EE)
7. Preparation Error (PE)

Moreover, Pierre Gy established the relative variance of the fundamental error, s^2_{FE}, can be estimated from the following equation (Eq. 3):

$$3\}\ s^2_{FE} = c\beta fgd^3\ (1/M_s) - (1/M_L) \qquad s^2_{FE} = \left(\frac{1}{M_s} - \frac{1}{M_L}\right) c\beta fgd^3$$

where:
s^2_{FE} = relative variance of the fundamental error,
M_s = mass of the sample, g
M_L = mass of the lot (population, sampling unit, area of concern), g
c = constitution parameter,
β = dimensionless liberation parameter,
f = dimensionless shape parameter,
g = dimensionless size range parameter, and
d = diameter of the largest particle, cm

However, since the mass of the sample is generally much smaller than the mass of the lot the formula can be reduced to:

$$4\} \qquad s^2_{FE} = c\beta fgd^3/M_s$$

This equation is often referred to as the FE equation for nuggets. The constitution parameter, c, depends upon the amount of the analyte of interest in the lot and the mean density of the lot (Gy

1998). If the amount of analyte of interest in the lot is small, analyte of interest <<1, then an approximation for the constitution parameter is given by:

$$5\} \qquad c = \delta_M / a_L$$

where:
c = constitution parameter,
δ_M = mean density of the lot, and
a_L = decimal fraction of analyte of interest in the lot.

The dimensionless liberation parameter, β, can have values from zero to one. The parameter is zero when the components are completely homogenized (an impossible situation) and is one when the components are completely liberated. It is best to set β = 1 if one is not certain of the state of liberation, which is typically the case with residues of MC. The dimensionless shape parameter, f, also can have values from zero to one. For a sphere f = 0.52. For most compact particles f has values near 0.5. The dimensionless size range parameter, g, also can have values from zero to one. Some values used in practice are:

Undifferentiated, un-sized materials mean value	g = 0.25
Undersized material passing through a screen	g = 0.40
Oversize material retained by a screen	g = 0.50
Material sized between two screens	g = 0.6/0.75
Naturally sized materials, e.g. cereal grains	g = 0.75
Uniformly sized objects, e.g. bearing balls	g = 1.0

Examples: Fundamental Error for Field Sampling

Based on assuming the following values for the parameters in Equation 4 for the relative variance of the FE: $\delta_M = 1.6$ g/cm^3 (a typically density for soil), β = 1 (as suggest above), f = 0.5 (also as suggest above), g = 0.25 (for un-sieved soils), and d = 0.2 cm (from the common definition of what constitutes soil, but is also potentially, the size of the contaminant of concern), one can solve for either the relative standard deviation of the FE or the mass of the sample, both to within a single significant figure, for anticipated situations. Some example calculations follow:

Example A: MIS Application:

If the concentration of the analyte of interest is 1 mg/kg (a_L = 1 e-06), then to theoretically achieve a relative standard deviation for FE of 15% (S^2_{FE} =0.225), the mass of the sample needs to be at least 71 kg. Likewise, for a 10 or 100 mg/kg concentration, 7.1 or 0.71 kg, respectively, of sample mass is needed to approach this level of total measurement uncertainty.

Conversely, if M_s = 2 kg (2000 g) and a_L = 1 e-04, 1 e-05 or 1 e-06, then the relative standard deviation for FE one could anticipate would be, respectively, 8.9%, 28%, and 89%.

Example B: Discrete Sampling Application:

If M_s = 180 g (mass of soil in a 4 oz jar) and a_L = 1 e-04, 1 e-05, or 1 e-06, then the relative standard deviation for FE is, respectively, 30%, 94%, and 298%. However, if only a 20 g aliquot is removed from the top of the sample container, uncertainty increases to 89%, 283%, and 894%, respectively, at these three concentrations. It should be noted that there are two fundamental errors associated with the overall error, the FE for field sampling, (which results in the mass of sample sent to the laboratory), and the FE associated with laboratory subsampling.

In the majority of cases it is impractical to estimate the FE based on a prior knowledge of the physical dimensions and shape factors associated with the MC of interest. These parameters must also include the sizes and shapes of non-MC particles in the sample as well. Indeed, the size distribution of particles is seldom known and their shape is often highly irregular and often unique. Perhaps in the case of lead shot, one could anticipate that MC would be round and of uniform density. One alternative is to estimate FE empirically, after dismissing the physical parameters in Equation 2. This can be accomplished for a sample lot based on the assumption that IH_L is the constant factor of constitutional heterogeneity (i.e., invariant or constant heterogeneity):

$$6\} \qquad S^2_{FE} = (1/M_S - 1/M_L)\ IH_L$$

where:
S^2_{FE} = relative variance of the fundament error,
M_s = mass of the sample,
M_L = mass of the lot (population, sampling unit, area of concern),
c = constitution parameter,
β = dimensionless liberation parameter,
f = dimensionless shape parameter,
g = dimensionless size range parameter,
d = diameter of the largest particle, and
$IH_L = c\beta fgd^3$.

Equation 6 then can be solved for IH_L

$$7\} \qquad IH_L = S^2_{FE}\ (M_S)$$

Under these conditions IH_L is the product of S^2_{FE} times the mass of the sample, moreover, if distributional error is minimized, S^2_{FE} can be estimated from the variance of several measurements of the sample lot (in this case a large field sample) as follows:

$$8\} \qquad S^2_{FE} \approx s^2 / \times^2$$

where:
S^2_{FE} = relative variance of the fundament error,
s = variance of several measurements of the sample lot, and

x = average soil concentration.

To minimize the distributional error variable within a sample without affecting the particle size of the matrix or of the constituents of interest, the sample is split into equivalent mass fractions, with a rotary splitter. With this apparatus, a sample of 1 or more kg, is incrementally split more than a couple thousand times, thus, more than 500 increments are combined in a single split. Table B-2 (found at the end of the appendix) shows estimated samples masses needed to achieve different levels of sampling uncertainty (15 and 30%) using this empirical approach. The range of sample masses estimated by this approach is in good agreement with those estimated above.

The theoretical and empirical estimations of uncertainty only assess the FE in the field during sampling. There is also FE associated with the laboratory processing and analysis phases of the analytical process. Therefore, to achieve even these levels (15 and 30%) of uncertainty, the entire sample (3 g to 70 kg) must be analyzed, i.e., no error can be attributed to these additional steps, which clearly is unreasonable. To allow for uncertainty to be introduced as a consequence of sample preparation and analysis, a target value of 15% uncertainty, for field sampling is recommended, and because the concentration often is not know a priori to sampling, a kg or larger sample size, is recommended. Moreover, it should be recognized in some cases even a 2 kg sample mass may insufficient to meet project DQOs.

This same equation can be used to look at the FE associated with taking a subsample using Methods 8330B and 3050B. As the subsample becomes smaller, uncertainty increases, particularly when the density of the COC is much greater than the matrix (e.g., Pb ρ = 11.4 g/cc) due to segregation error. Assessment of segregation error is beyond the scope of this document. However, segregation error is a possible explanation for the much greater uncertainty associated with Pb as compared to energetic residues, for a given concentration (Table B-2). Even for energetic residues, e.g., TNT and Comp B, with densities of around 1.8 g/cc, depending on the formulation and manufacturing, a density that is similar to soil, 2 to 10-g subsamples of unprocessed materials, results in an unacceptable level of uncertainty, except when concentrations are exceed 1000's to 10,000's of parts per million (e.g., 0.1 to 1% w/w, see Table B-2).

Example C: Fundamental Error for Laboratory Sub-Sampling

A. For samples, that are sub-sampled in the laboratory, but not ground, but are <2 mm:

If M_s = 1 g (mass of soil for a typical metals digestion) and a_L = 1 e-04, 1 e-05, or 1 e-06 then the fundamental error is, respectively, 400, 1265, 4000%.

If M_s = 10 g (mass of soil for Method 8330B) and a_L = 1 e-04, 1 e-05, or 1 e-06, then the fundamental error is, respectively, 126, 400, 1265%.

B. For samples comminuted (ground) to <0.075 mm (<0.0075cm), and then sub-sampled (i.e. for EPA 8330B):

If M_s = 1 g (mass of soil for a typical metals digestion) and a_L = 1 e-04, 1 e-05, or 1 e-06, then the relative standard deviation for fundamental error is, respectively, 3, 9, 30%.

If M_s = 10 g (mass of soil for EPA 8330B) and a_L = 1 e-04, 1 e-05, or 1 e-06, then the relative standard deviation for fundamental error is 0.9, 3, 9%.

Clearly, if samples are not ground to a fine powder, and concentrations below 100 mg/kg are important, either numerous aliquots ($n \geq 12$) are needed to to obtain a reasonable estimate of the average concentration, or no reasonable degree of confidence can be associated with the data. Even at concentrations in the 1000 mg/kg (0.1% w/w), the uncertainty is on the order of 100%, when the analytical method recommends a 1-g subsample. Contrarily, if the entire sample is ground, reasonable levels of precision can be obtained. Furthermore, accuracy can be demonstrated for energetic residues, based on whole sample extraction (Table B-1), or can be strongly inferred by the extraction and analysis of 15 replicate subsamples, in the case of metals.

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Table B-1. Comparison between bulk sample concentration and average subsample concentration after Method 8330B processing.

Location / Sample	Portion	Mass (g)	Acetone (mL)	Concentration (mg/kg)					
				Statistic	HMX	RDX	TNT	2,4-DNT	NG
Demolition Range (MI-9)	Bulk	1766	3540		**2.02**	**11.9**		**4.81**	
	R1	10.0	20.0		1.98	11.7		4.58	
	R2	10.0	20.0		2.00	11.6		4.92	
	R3	10.0	20.0		1.98	11.8		5.22	
				Ave	**1.99**	**11.7**		**4.91**	
				Std Dev	0.009	0.090		0.320	
				%RSD	0.48%	0.77%		6.53%	
				RPD *	**1.4%**	**1.7%**		**2.1%**	
Firing Point Fox (MI-10)	Bulk	1196	2400						**4.21**
	R1	10.0	20.0						4.00
	R2	10.0	20.0						5.04
	R3	10.0	20.0						4.06
				Ave					**4.37**
				Std Dev					0.584
				%RSD					13.4%
				RPD					**3.7%**
Low Order #3 (MI-5)	Bulk	1278	2560		**2.76**	**14.3**	**1.56**		
	R1	10.0	20.0		2.72	14.1	1.60		
	R2	10.0	20.0		2.72	14.1	1.60		
	R3	10.0	20.0		2.60	13.9	1.63		
				Ave	**2.68**	**14.0**	**1.61**		
				Std Dev	0.035	0.125	0.016		
				%RSD	1.26%	0.89%	1.00%		
				RPD	**2.9%**	**2.1%**	**3.2%**		
Hand Grenade Range (MI5)	Bulk	2526	5060			**0.645**			
	R1	10.0	20.0			0.592			
	R2	10.0	20.0			0.598			
	R3	10.0	20.0			0.576			
				Ave		**0.589**			
				Std Dev		0.011			
				%RSD		1.93%			
				RPD		**9.1%**			
Firing Point Juliet Tower (MI-5)	Bulk	1935	3880					**0.964**	**2.97**
	R1	10.0	20.0					0.88	2.38
	R2	10.0	20.0					1.09	2.84
	R3	10.0	20.0					1.17	3.36
				Ave				**1.05**	**2.86**
				Std Dev				0.152	0.490
				%RSD				14.5%	17.1%
				RPD				**8.5%**	**3.8%**

* RPD - Relative percent difference between average and bulk concentration.

Table B-2. Estimates of field sample mass required to achieve either a 15 or 30% uncertainty, based on P. Gy sampling theory, i.e., constant factor of compositional heterogeneity (IHL). Energetic residues were from MIS samples collected on impact ranges and at a firing point. Those with metals were collected on the face of an earthen back stop for a small arms range.

Mass of Sample Splits (n=12) Aver ± Std Dev*	Analyte	Average Conc. (mg/kg) ± Std Dev	Sampling Uncertainty 15% RSD**	Sampling Uncertainty 30% RSD
203±4.5	RDX	1.7±1.8	10 kg	3 kg
200±6.5	RDX	2.1±0.96	2 kg	0.5 kg
203±6.1	2,4-DNT	1.0±0.73	5 kg	1 kg
†200±6.5	2,4-DNT	4.5±1.6	1 kg	0.3 kg
200±6.5	NG	1370±46.8	0.01 kg	0.003 kg
203±4.5	NG	1650±82.4	0.02 kg	0.006 kg
203±7.9	Pb	200±94	2 kg	0.5 kg
200±5.8	Pb	1380±189	0.2 kg	0.05 kg

* Standard deviation ** Relative standard deviation † Walsh et al., Soils and Sediments

Appendix C. A Practical Guide to Sampling

(This Appendix was originally published in **MMRP GUIDANCE DOCUMENT FOR SOIL SAMPLING OF ENERGETICS AND METALS)**

Safety Considerations

In areas where UXO, discarded military munitions, or materials potentially presenting an explosive hazard are present or may exist, field activities are supervised by military EOD personnel or qualified UXO technicians. The on-site UXO technician will conduct a surface access survey and a subsurface survey for anomalies before any type of activities commence, including foot and vehicular traffic. Procedures for these measures should be described in the Contractor's Site-Specific Work Plan and modified in their site-specific plans as required.

Although uncommon, soils containing energetic compounds at concentrations that present risk of detonation or deflagration, exceeding 100,000 mg/kg (10%), may be encountered in the vicinity of ruptured munitions or partial detonations (low-order) on ranges, at manufacturing facilities, or in disposal areas such as OB/OD sites, and near burial pits. In these areas pieces of explosives are often seen on the ground. TNT is yellow but turns reddish brown when exposed to sunlight and often has a reddish halo on the soil surrounding the solids. RDX is white to light yellow but does not photo-degrade to form red compounds. Consequently, Comp B is less highly colored than TNT as it only has ~40% TNT in this formulation. Pieces of C4 explosive are often encountered where blow-in-place has been used to destroy UXO or where demolition training has occurred. Pieces of C4 are white in color. Visible or otherwise identifiable pieces of explosive compounds should not be incorporated into the soil samples. The EXPRAY Kit (Plexus Scientific, Silver Springs, MD) or EPA Methods 8515 and 8510 (US EPA 1996, 2000) may be useful for screening suspected explosive material or potentially very high concentrations in soil before sampling and shipping soil samples off site.

Sampling Tools

An unbiased sampling scheme must be developed and carefully followed to uniformly sample the volume of soil within the boundaries of the sampling unit. The fundamental requirements for increment collection are:

- an unbiased pattern throughout the entire sampling unit
- complete and uniform sampling across the specified depth interval
- uniform size/mass of increments

A sampling methodology is considered unbiased if all of the particles in the sampling unit have the same probability of being included in the sample (Gy 1998). To obtain a sample that is representative of the population in terms of particle type, size, and proportion, the volume of soil in each increment must be constant.

Coring devices that assure a uniform diameter core through the entire sampled interval are preferred for increment collection. Most devices such as a garden trowel or hand auger do not control the amount of material per increment or ensure representative proportions of material from throughout a specific depth interval. They are likely to introduce bias into the sampling, particularly when more than one sampler is involved in sample collection. Although their use may be unavoidable for coarse gravelly soils, such tools are not recommended (Pitard 1993).

A variety of hand operated coring devices designed for surface sampling (e.g. < 6 inch depth) are widely available from a various vendors. "Pogo-stick"-type coring devices patterned after prototypes designed by CRREL (Fig. C-1). Where suitable cohesive soils are present, a coring device makes it easier and faster to collect uniform, representative increments from a consistent depth interval. For highly compacted or cemented soils, split barrel samplers with a drive shoe

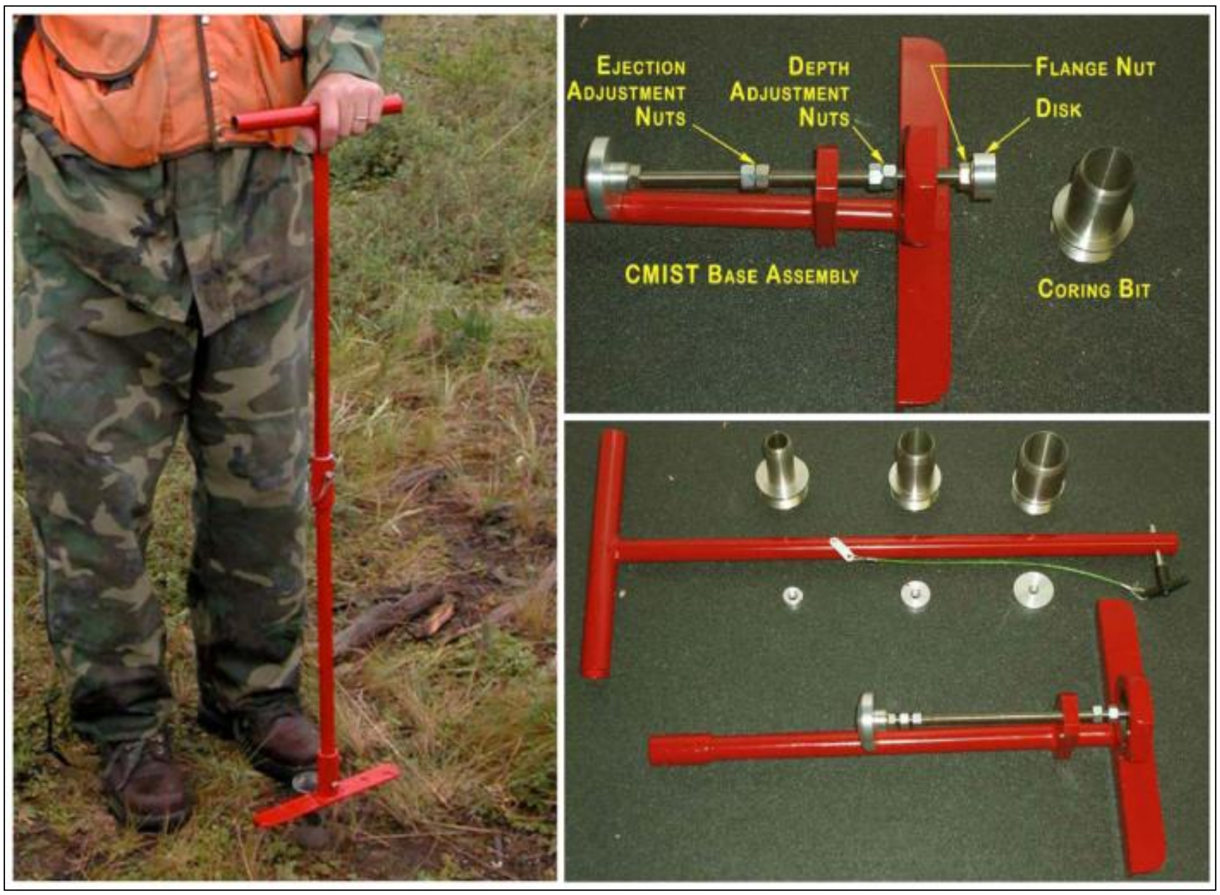

Figure C-1. CRREL Coring Device (CRREL 2004a; CRREL 2009). Note various size coring shoes. Increment cores from a single Sampling unit should be of the same size can be driven manually using a slide hammer or used with a direct push drill rig. They may work well for deeper samples. Graduated plunger devices or coring devices such as an Encore sampler will provide a consistent volume for obtaining increments from conventional deeper cores (e.g. split barrel, Shelby tube, etc.). The diameter of the cores should be adjusted to obtain a total dry weight sample mass of 1 kg to 2 kg for the prescribed number of increments. Keep the tip of your sampling tool sharp. In the case of the CRREL corer the tip is made of stainless steel. Although stainless steel does not react with most analytes, it is not hard and will deform when sampling coarse soils or encountering rocks.

Project planning should provide discussion of sample collection and identify contingency actions in case sample collection difficulties are encountered. Taking a wide variety of implements into the field may help ensure the greatest likelihood of successful sample collection.

Determining Sample Size and Number of Increments Required

To ensure that the multi-increment sample will not "miss" contamination of concern within the sampling unit, a sufficient number of increments need to be collected. The number of increments required to obtain a representative multi-increment sample and to meet the required level of reproducibility specified in the DQOs, depends on the distributional heterogeneity of analytes within the sampling unit. The number of increments required to represent a sampling unit is not directly related to the size of the sampling unit but depends only on the degree of the variability within the sampling unit. (In statistics, the number of measurements required to characterize a population does not depend on the size of the population, but on the variability of the population.) There is, however, a general correlation between size and variability because a larger sampling unit potentially encompasses greater variability. For example, large sampling units on an impact range may be more likely to contain multiple low-order detonations. In choosing the size of the sampling unit, consider the mode of contamination.

Field studies show that 50 to 100 increments are required to achieve good reproducibility (e.g. %RSD <30) among replicates at active firing ranges where energetic compounds are heterogeneously distributed. Statistical investigations also support this number of increments for acceptable reproducibility (US EPA 2003). Just as increasing the number of discrete samples analyzed from a given area reduces the variability of the estimated mean concentrations of the area, increasing the number of increments for a multi-increment sample reduces the variability of the estimated mean concentrations among replicate multi-increment samples. However, increasing the number of increments above 100 provides only marginal improvement in precision in most cases.

The number of increments must be balanced with the mass of each individual increment to yield a total sample mass that is sufficient to overcome the compositional heterogeneity of the soil (Table C-1). Adequate total sample mass for typical soil-size particles (< 2 mm) has been empirically demonstrated to be 1 to 2 kg (based on analyses of explosives).

The number of increments per unit area should be the same for sampling units that will be compared directly to each other, or to the same decision criteria. This will help assure that the results being compared have the same precision from the different sampling units. It also will support application of the precision determined by replicate sampling of one sampling unit to similar units that were sampled at the same increment spacing.

Table C-1. Number of increments collected using different coring device diameters to obtain a given sample mass. Highlighted in yellow is the optimum range (Walsh 2009).

Corer Diameter (cm)	Sample Mass* (g)		
	1,000	**1,500**	**2,000**
	Number of increments to reach sample mass (g)		
1.00	340	509	679
1.25	217	326	435
1.50	151	226	302
1.75	111	166	222
2.00	85	127	170
2.25	67	101	134
2.50	54	81	109
2.75	45	67	90
3.00	38	57	75
3.25	32	48	64
3.50	28	42	55
3.75	24	36	48
4.00	21	32	42
4.25	19	28	38
4.50	17	25	34
4.75	15	23	30
5.00	14	20	27

* Assumed: Dry bulk soil density = 1.50 g/cc, increment core length = 2.5 cm

Multi-increment Collection Design

The systematic random sampling design is best suited for multi-increment sampling. Using this technique, uncertainty in the data can be quantified by collecting replicate samples. Other sampling designs and probabilistic sampling schemes are described in the EPA guidance document QA/G-5S (US EPA 2002).

The systematic random approach is the most commonly used and most reproducible sampling pattern (Fig. C-2). The key steps for collecting this type of sample are:

- Sub-divide the sampling unit into uniform grid cells, 100 cells if you want to take 100 increments.
- Randomly select a single increment collection point in an initial grid cell.
- Collect increments from the same relative location within each of the other grid cells.

When collecting replicate samples, randomly select a different starting point in the first cell and build a sample with increments from that relative position in each grid cell.

This process is quite straightforward in a square- or rectangular-shaped sampling unit. When the shape of the area to be sampled is irregular, a systematic random sample can still be collected as shown in Figure C-3. The sampler walks along lanes with defined spacing and collects increments at a specified interval. An explanation of how to determine sample spacing in this case is discussed below.

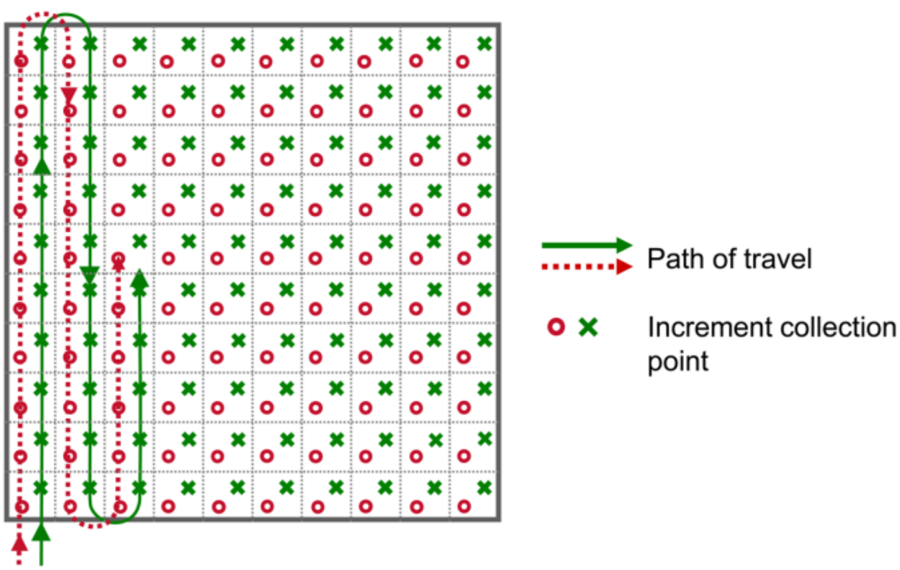

Figure C-2. Systematic random sampling pattern for collecting two (replicate) 100-increment samples in a square sampling unit.

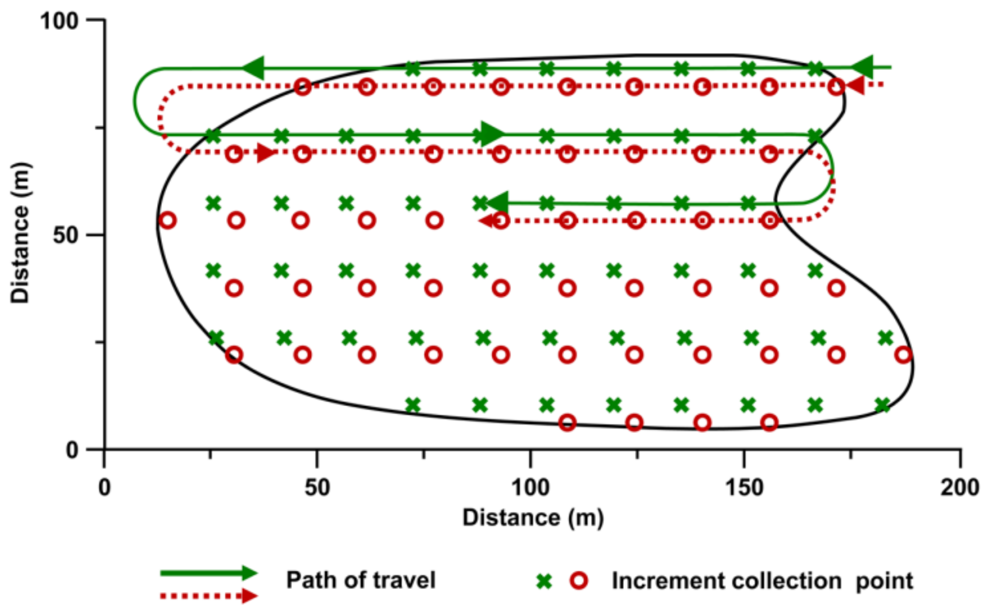

Figure C-3. Pattern of systematic random sampling for collecting two (replicate) 50-increment samples in an uneven-shaped Sampling unit, located within the solid black line.

Setting up the Sampling unit

Establish Sampling unit Corners.

We describe here how to establish the corners of a square sampling unit, using a 10 × 10-m sampling unit as the example (Fig. C-4); this is easily modified for any rectangular shape. Step 1: Place a flag (or painted lath) at Corner A and use either a measuring tape or a rangefinder (for larger Sampling units) to establish a baseline 10 m in length to the second flag at Corner B. Step 2: Swing the tape 90° to get an orthogonal side 10 m from Corner B to the approximate location of Corner C. To verify perpendicularity and the correct position of Corner C, use a second tape (or rangefinder) on the diagonal from Corner A to Corner C, calculating the appropriate diagonal length using $AB^2 + BC^2 = Diag^2$ (in this case, the diagonal equals 14.14 m). Mark the position of Corner C where the two tape end points from Corners A and B coincide. Step 3: Move the tape used to measure the diagonal to Corner B and use the same principle and two tapes, diagonal from Corner B and 10 m from Corner C to establish Corner D, maintaining the length of BD equal to 14.14 m. Step 4: Check (and adjust) the location of Corner D by verifying the length from Corner A to Corner D is 10 m (in this case).

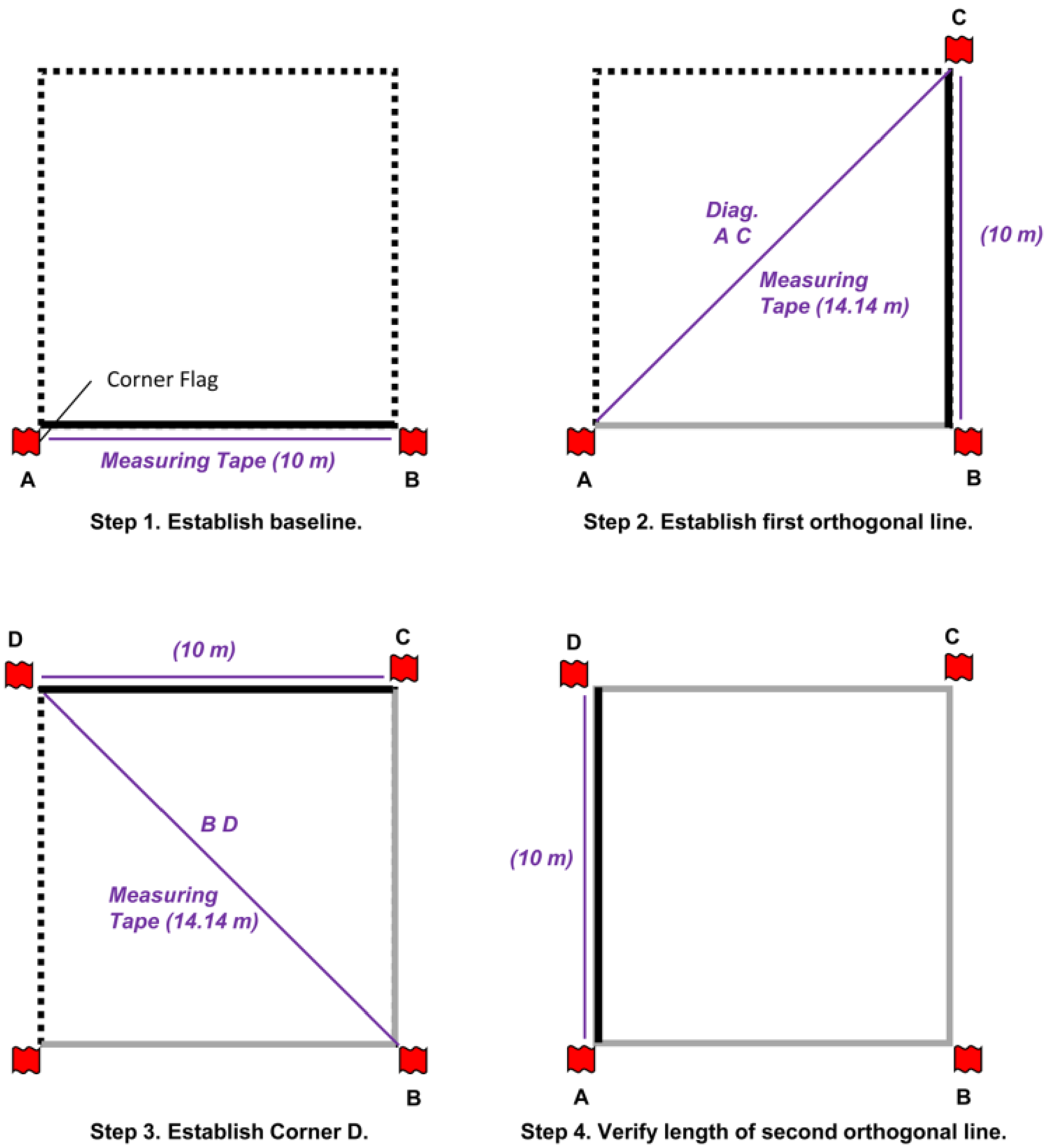

Figure C-4. Steps to layout a rectangular sampling unit. The side being defined is shown as a thick black line. Positions of the measuring tape used to define corner locations are shown as thin purple lines.

Determine Lane Spacing and Markers

The next step is to determine the number of lanes within the sampling unit and the increment spacing per lane to collect the proper number of sample increments. Our goal is to develop a pattern with evenly spaced sampling points. The following describes an approach to design this pattern.

This example determines sample spacing based on the assumptions:

- the sampling unit is a 10 × 10-m square,
- a systematic-random sampling pattern, and
- at least a 50-increment sample.

First determine the square root of the number of increments: $\sqrt{50} \cong 7.07$, then divide the length of a side in the Sampling unit by the square root you just calculated: 10 m / 7.07 = 1.41 m. This calculation indicates that the distance between sampling lanes should be 1.41 m. However, marking lanes every 1.41 m would result in (10/1.41) or 7.1 lanes. Although a 7.1 × 7.1 division does provide 50 sampling cells (one for each increment), the number of lanes must be a whole number. In this case, a good choice would be to have seven lanes (1.42 m wide) along one axis, and collect eight soil increments along each lane at 1.25-m spacings (10 m/8 = 1.25 m). This design provides 56 cells a few more than our target of 50-increments (Fig. C-5). The size of other sampling units and the number and placement of increments can be estimated in a similar way.

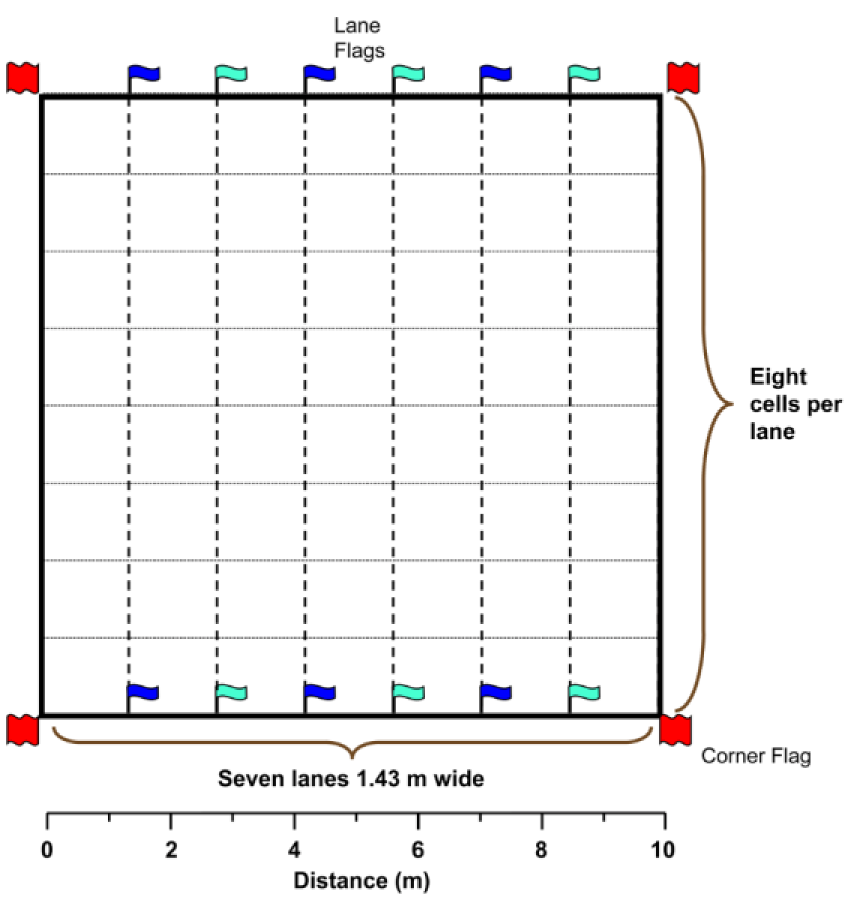

Figure C-5. Sampling unit divided into seven lanes with eight cells in each lane. Placing alternating colored flags at the intersections of lanes helps with visualizing the walking path.

Once the number of lanes is established, mark the division between lanes with a pin flag or some other indicator. Plastic-stemmed flags are better than metal-stemmed pin flags as they do not interfere with magnetometer readings. It is helpful to use flags with two colors and alternate them to help samplers walk the correct path (Fig. C-5).

Collecting the Sample

Once the sampling unit and lane positions are marked, the first step in collecting the sample is to determine your first increment collection point within the starting cell. This must be done randomly, using a random number generator, a calculator or a die. Two numbers are needed to define the sample location within the cell (an X and a Y coordinate starting from a corner of the sampling unit). It is best to choose a manageable number of divisions for the cell. In our example, the cell dimensions are 1.42 m in the X direction and 1.25 m in the Y direction. You could choose to use six divisions in each cell, which in this case for the X direction would be 0, 0.28, 0.56, 0.85, 1.14, 1.42 m, and in the Y direction would be 0, 0.25, 0.5, 0.75, 1.0 and 1.25 m. (A number on the die can be used to represent one of the choices, e.g. 1 = 0, 2 = 0.5, and so on.) Figure C-6 shows an example in which the lower left-hand corner is the starting cell, the origin position within that cell (x=0, y=0) is its lower left-hand corner, and the collection position for the first increment is x= 0.85 and y= 0.25 as shown by the green "×" symbol.

After collecting the first increment at that position, all subsequent increments should be positioned as close as possible to the same location within each cell as illustrated by the other green "×" symbols in Figure C-6. Using the flags as aids, start in one corner of the sampling unit and collect increments up and back along the marked lanes as shown schematically in Figure C-6. Offset the location of an increment, by as little as possible, if you encounter a rock outcrop or tree roots. Figures C-2 and C-3 show how to take two MI samples from the same sampling unit. Here again, randomly choose your starting sampling point and then collect increments from the same location within each cell.

Another useful aid to help samplers stay in the proper lane is a wooden lath with colorful flagging attached. One "end of lane marker" is used on each end of the sampling unit (Fig. C-7). Position the lath at the far end of the upcoming sampling lane. When you reach the end of that lane, move the lath two lanes over before collecting down the adjacent lane, as shown in Figure C-7. End of lane markers are especially helpful for sampling sampling units with uneven terrain or tall vegetation but we use them routinely as they save time and help the samplers follow their lane.

Sampling in teams of two allows one person to collect the soil increments while the other holds the sample bag and keeps count of the number of increments (Fig. C-8). A small mechanical counter is handy for keeping track of the number of increments, as it is easy to lose count.

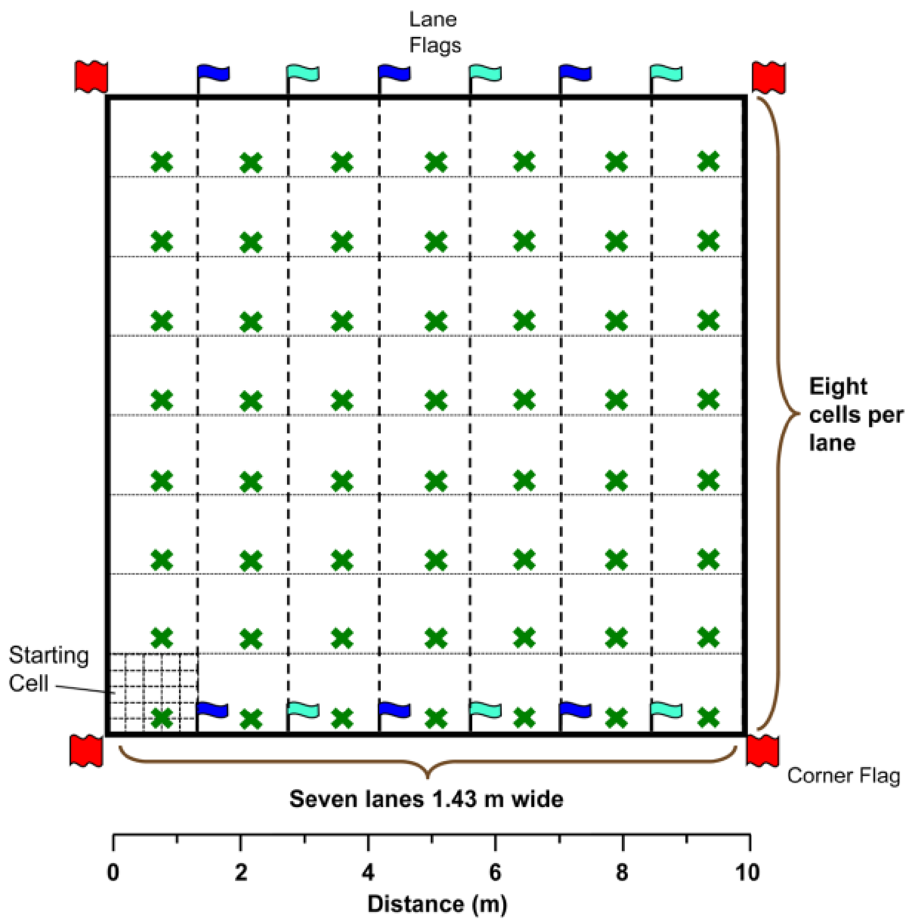

Figure C-6 Systematic random collection pattern for a 56-increment sample in a 10 x 10-m square sampling unit. Increment locations designated by the green x symbols. Increments should be collected at the same relative position within each collection cell.

Results will be more consistent if each person does the same job for all replicates. You do not need to clean the sampling tool between increments within a sampling unit or between replicate samples within a sampling unit. The tool must be decontaminated before sampling a new sampling unit. Rinseate blanks can be taken between sampling areas but the concentration in these blanks is typically negligible.

We use clean polyethylene sampling bags rather than sample bottles for MI samples (Fig. C-8). Label the outside of the sample bag and the tag that will go on the outside of the sample bag, and record in a logbook sample information such as date, site, sampling unit, # of increments, increment diameter and depth, replicate #, and name of sampler. Decide upon and document a labeling and numbering scheme before going to the field. Double bag the sample after collecting to reduce cross-contamination during sample storage and shipment. A good procedure is to use a cable tie to close the bag and attach the identification tag. Photos are extremely helpful and provide visual documentation. A list of sampling supplies is in Table C-2, which is positioned at the end of this Appendix.

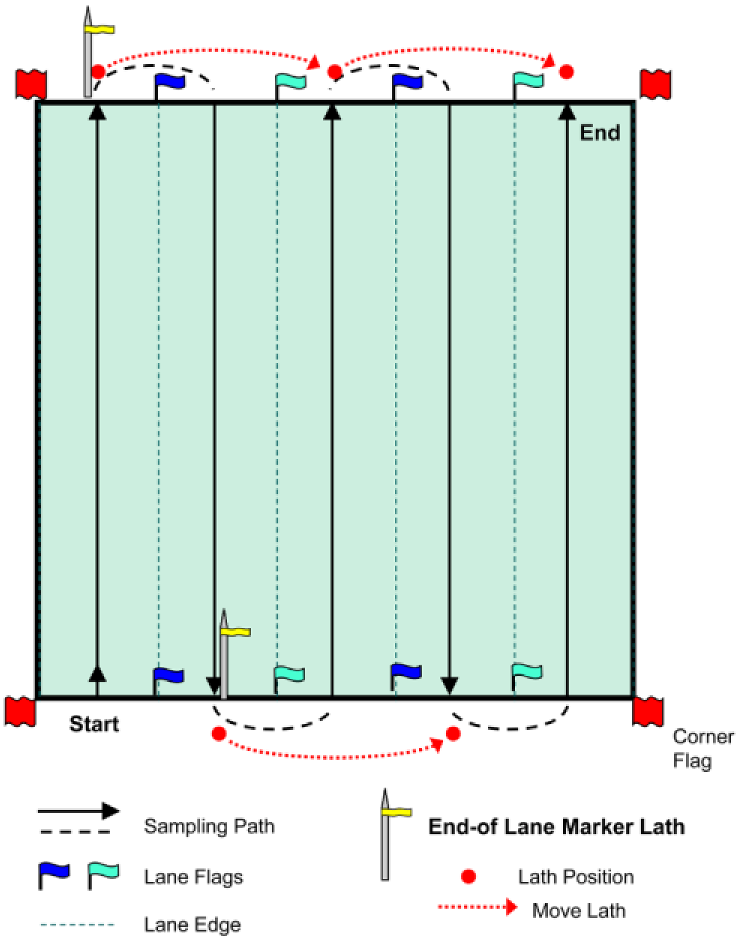

Figure C-7 Schematic of a typical walking path traversed while collecting a multi-increment sample in a square sampling unit. Increments are collected along the solid black line, traveling to the next lane is shown as a dashed black line. A marker lath is used on each end to help accurately position increment locations. The lath is moved to every other lane on each side.

Figure C-8. Photo of a two-person team collecting a multi-increment sample.

Note: Once collected in the field, it is tempting to split the samples and only send a small portion of each sample to the laboratory. Do NOT split the sample. Hewitt et al. (2009) studied the magnitude of field splitting error and found it to range from 4.7 to 120% with a median value of 43.1%. Such a high error necessitates shipping the entire 1 to 2 kg sample to the laboratory for processing and analysis.

Additional Considerations for Irregular Shaped Areas

To determine an appropriate sample spacing for collecting an IS from an unevenly shaped sampling unit using a systematic random pattern (e.g. Fig. C-3), you must first estimate the area to be sampled. If known in advance, you can do this prior to arriving at the sampling site with a GIS or air photo. If this is done on site, use a measuring tape or rangefinder to temporarily divide the area into multiple small rectangles and triangular shaped units and determine their individual areas, then sum them to determine the total area, *A*. Next, determine the theoretical length, *L*, that a side would have if the equivalent area were a square by taking the square root of area *A*.

$$L = \sqrt{A}$$

Then, find the increment spacing, *S*, using the same logic as presented earlier for a square sampling unit. This is done by dividing your theoretical "side" length by the square root of the number of increments, *N*:

$$S = L/\sqrt{N}$$

The next step would be to establish an appropriate number of lanes traversing the long dimension of the sampling unit and collecting increments at the spacing just determined. It is important to keep the increment spacing as even as possible throughout the space sampled. The exact number of increments is not as critical as obtaining the minimum number determined by the DQOs. The method described above can also be used to determine sample spacing in rectangular shaped sampling units.

Collecting samples around ruptured rounds

Because a partially detonated bomb, a dumpsite, a ruptured munition, or other ordnance item will have contaminant concentrations significantly higher than the other areas in a site, they should be sampled as separate sampling units. The sampling unit should encompass the area of any visible residue chunks and any surface discolorations. EOD personnel or UXO technicians should remove any chunk explosives (these should be weighed separately) so they are not inadvertently incorporated into the sample. To prevent cross contamination, samples collected where chunk residues were present should be double bagged and segregated from other samples during transportation, storage, and laboratory processing (US EPA 2006, page A-13).

When ordnance disposal (blow-in-place) coincides with site characterization activities, pre- and post-detonation multi-increment samples can help establish if residual MC is pre-existing or due to the blow-in-place operation, or both (Pennington et al. 2008; USACE 2007). This is more likely at the RI stage during intrusive operations, and during removal and remedial actions.

How to deal with vegetation in a sample.

Appendix A of EPA Method 8330B recommends including surface vegetation and plant matter in the sample increments from active ranges. However, vegetation should be included only if necessary to satisfy DQOs, for example if the study is trying to determine the total amount of a contaminant deposited by airfall onto a recently used range. If vegetation is included, it remains with the sample until it is sieved. During this step the vegetation should be broken in smaller pieces to release trapped particles. The majority of vegetation does not pass through the sieve and therefore is not part of the sub-sample extracted for analysis.

At MMRP sites or other sites where surface vegetation clearly post-dates any contaminant release, vegetation in the sample should be removed during laboratory processing. Note that some types of vegetation, i.e. mosses, can be long-lived. Do not bias your samples trying to avoid vegetation. At MMRP sites, dissolved contaminants may have migrated deeper into the soil, or contaminant particles buried or transported by post-release processes. These factors should be considered and described when delineating Sampling units at MMRP ranges.

Sub-surface sampling

Range characterization studies show that the highest concentrations of energetic compounds are at firing positions, near targets, and where demolition activities are performed (Hewitt et al. 2007, Jenkins et al. 2006) and that most of the energetic residues remain on the surface (Figure C-9). Sub-surface sampling may be needed for ranges where the surface has been physically altered, where energetic residues are found on the surface at high concentrations, and to address human risk concerns when soils are excavated during construction activities. At demolition and disposal and hand grenade ranges, where a common management practice is to periodically fill craters, energetic residues are found at depth. Energetic residues can also be buried when surface soils are removed, redistributed or covered with clean soils. Generally contaminants dissolved by precipitation are not detectable in subsurface soils because they are only present within the small amounts of soil moisture.

The best way to sample the distribution and concentration of energetic compounds in three dimensions has yet to be determined. We recommend taking multi-increment samples, although we recognize that these samples can be difficult and time consuming to collect. Depending on the DQOs depth profiles can be collected in 10-cm intervals down to a depth of at least 30 cm. Sample increments from the same 10-cm depth interval (0–10 cm, 10–20 cm, and 20–30 cm)

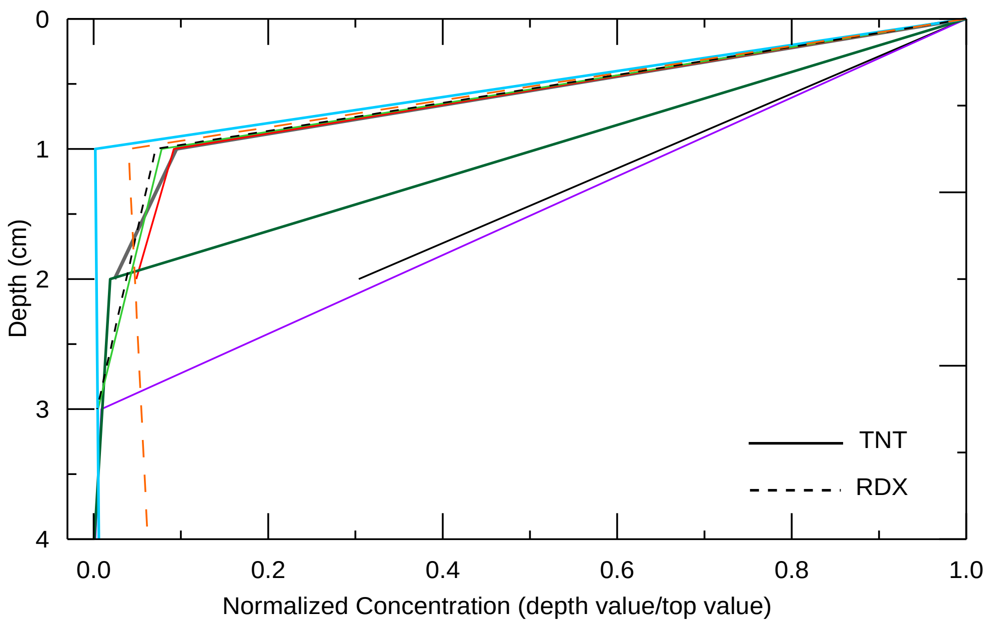

Figure C-9. Normalized profile showing decreasing concentration in energetic compounds with depth directly beneath seven TNT chunks (> 2 cm) found on the surface at Fort Bliss and two chunks of Composition H-6 at 29 Palms. Equivalent samples are shown in the same color.

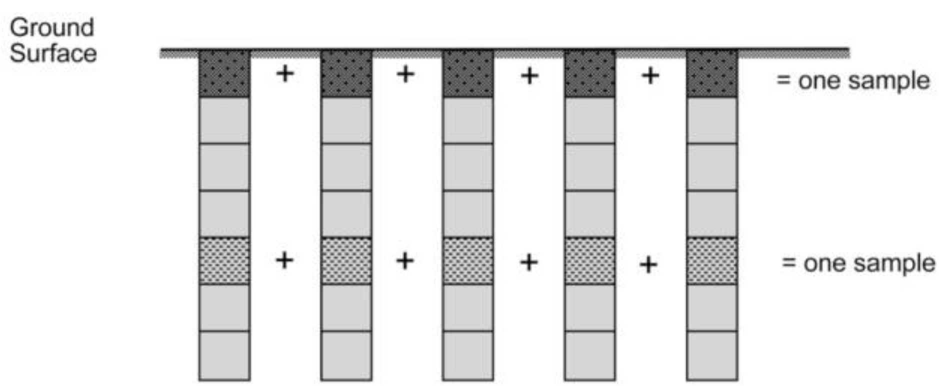

Figure C-10. A schematic showing how increments from equivalent depth intervals are combined into a multi-increment sub-surface sample.

should be combined to produce a multi-increment sample (Fig. C-10). The depth intervals sampled (lifts) need not be 10 cm as in the example given above but can be 2 cm or 30 cm depending on the information required. If only a few depth profiles are combined, the data might be suited for determining the depth to which residues have been mixed into the soil profile but not to estimate the average concentration for a subsurface layer over a large horizontal cross-sectional area. To achieve this second objective, 50 to 100 increments should be collected. For depths below 30 cm, a surface geophysical survey may not be sensitive enough to detect UXO; therefore, down-hole clearance must be performed.

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Table C-1: Soil Sampling Field Kit supplies

Items in **bold** font are essential.

Item Description	Qty*	Purpose	Source / Part Number**
Sampling Tools			
Coring tools		*Obtain soil sample increments*	
Coring tool	(1)		CRREL or Centauri Labs
2-cm-diameter coring bit	1		
3-cm-diameter coring bit	2		
4-cm-diameter coring bit	1		
Support Tools and equipment		*Adjust and repair coring tool*	
Wrench, 9/16"	2	Adjusting lock-nuts	M-C # 5400A18
File, metal, half-round	1	Sharpening ID of coring bit	M-C # 6073A11
Hammer, Dead-blow, 1#	1	Ejecting stuck core	M-C # 6051A31
Pliers, slip joint, 2.25"	1	Installing coring bits	M-C # 5368A14
Pin, 5/16 x 1.25"	1	Spare connecting pin	M-C # 93750A402
Tool, multi-purpose	1	Handy for many tasks	(e.g. Leatherman)
Nuts, Hex, SS, 3/8-24	4	Replacements	
Nuts, Flange, Serrated, SS, 3/8-24	2	Replacements	
Tape Measure, Metric, 3-m	2		M-C # 68025A55
Splitting tools		*Used to subsample cores*	
Putty Knife (Modified)	1	Sharpen one edge, tooth the other	M-C # 3658A13
Putty Knife	1		M-C # 3658A31
Scoops		*Used where corers do not work*	
Stainless #2	2		AMS #428.02 or 427.82
Cleaning Equipment and Supplies			
Equipment		*Durables*	
Stainless steel pads	6		M-C # 7364T75
Brush, parts-cleaning	1		M-C # 7448T67
Bottle, spray, 16 oz	1	For Acetone	M-C # 9864T52
Bottle, spray, 4-L	2	For Water	M-C # 9864T15
or **Sprayer, compression**	1	For Water	M-C # 9864T15
Bottle, HDPE, 4-L	2	Extra water storage	M-C # 7528T36
Pail, 20-L, w/ cover	1	Field waste storage	M-C # 4344T71
Supplies		*Disposables*	
Kimwipes or Techwipes	2		M-C # 7036T12
Acetone		0.5 to 1L should work.	
Sample Collection Materials			
Decision Unit demarcation		*Marking area to be sampled*	
Flagging, PVC stake	24	Color, qty, and size discretionary	FSI # 33702
Wrench, Allen, T-handle,	2	For setting pin flags in hard soil	M-C # 5374A55
Stake, survey, 4-ft	6	Marks corners and active lanes	
Tape measure, 30-m	2	Lay out DU	FSI # 39941
Tape measure, 8-m	2		FSI # 39415
Rangefinder, Nikon 1200 7 x 35	1	11 - 1200 yd	Eagle Optic # RAN-NK-8358
Flagging, roll, pink, orange	2	For marking avoidance items	FSI # 57905

Soil Sampling Field Kit components and supplies (cont.).

Item Description	Qty*	Purpose	Source / Part Number**
Sample Collection Materials, cont.			
Collection		*For field samples*	
Bags, clean, PE, 15"x 15", 6 mil	100	(EPA Level 100 clean)	KNF # 300010-02 (LB 106:1515)
or **Bags, clean, PE, 17"x 12", 6 mil**	100		KNF # 300010-02 (LB 106:1217)
Ty-wraps, black, ss tongue	200	For bags and tags	M-C # 6614K54
Tags, 2.5"x 5" self-laminating	120		Brimar (Ref. Invoice #96886)
Counter, handheld, pushbutton	2	For keeping track of increments	M-C # 1707T5
Personnel Protective Equipment		*Visibility and worker protection*	
Gloves, latex, diamond-grip	20	Hand protection (sized M, L, or XL)	C-P # EW-86231-31, 32, or 33
Vest, surveyors		(High-visibility orange)	
Site-specific (masks, etc.)		Dependent on area of operation	
Documentation			
Book, recording, level	2	Field sample logging and notes	FSI # 49496 (Rite-in-the-Rain ®)
Marker, black, fine-point, permanent	6	Marking bags and tags	(Sharpie)
Marker, black, X-fine point	6	Field book and tags	
Other			
Container, storage, lockable	2	To carry kit	(Rubbermaid Action-Packer, 24-gal)
Locks, keyed-alike	4	To lock the storage boxes	M-C # 1834A36
Water bottles		For personal use	

* Quantities shown recommended for each tool;

** Sources: M-C: McMaster-Carr; AMS: Art's Mfg. & Supply Inc. (http://www.ams-samplers.com/); FSI: Forestry Suppliers, Inc. (http://www.forestry-suppliers.com/); KNF: KNF Clean Room Products, Corp. (http://www.knfcorporation.com/); Brimar: Brimar Industries Inc. (http://www.brimar.com/); C-P: Cole-Parmer, Inc. (http://www.coleparmer.com/); GPL: GPL Laboratories, LLLP; Undesignated items are locally available.

FRANKHAM-1998-CONSERVATION BIOLOGY

Inbreeding and Extinction: Island Populations

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Abstract: *Island populations are more prone to extinction than mainland populations, with island endemic species having higher extinction rates than nonendemic species. Inbreeding depression is one possible explanation for this. Insular populations are expected to suffer increased inbreeding relative to mainland populations due to bottlenecks at foundation and to lower subsequent population sizes. Inbreeding coefficients for 182 nonendemic and 28 endemic island populations were estimated from allozyme and microsatellite heterozygosities in island and related mainland populations. Island populations were significantly inbred, with inbreeding coefficients significantly higher in endemic than nonendemic island populations. Many island populations showed levels of inbreeding associated with elevated extinction rates in domestic and laboratory species. Inbreeding depression cannot be excluded as a factor in the extinction proneness of island populations.*

Intracruza y Extinción: Poblaciones Isleñas

Resumen: *Poblaciones Isleñas presentan una mayor tendencia a la extinció que las poblaciones continentales, teniendo las especies endémicas una mayor tasa de extinción que las especies no endémicas. La depresión por intracruza es una explicación posible a esto. Es de esperarse que poblaciones insulares sufran una intracruza relativemente mas alta que las poblaciones continentales debido a cuellos de botella a nivel de tamaño poblacional de fundación y subsecuentes tamaños poblacionales menores. Los coeficientes de intracruza para 182 poblaciones no endémicas y 28 poblaciones endémicas se estimaron mediante heterozigocidades de alozimas y microsatélites de poblaciones de islas y especies continentales relacionadas. Las poblaciones isleñas estuvieron significativamente intracruzadas, con coeficientes de intracruza signifiativamente mayores en poblaciones endémicas que en las poblaciones no endémicas. Muchas poblaciones isleñas mostraron niveles de intracruza asocidos con elevadas tasas de extinción en especies domesticas y de laboratorio. La depresión por intracruza no puede ser excluída como un factor en la tendencia a la extinción de especies isleñas.*

Introduction

Island populations have much higher risks of extinction than mainland populations (Diamond 1984*a*, 1984*b*; Vitousek 1988; Flesness 1989; Case et al. 1992; World Conservation Monitoring Centre 1992; Smith et al. 1993). Of animal extinctions since 1600, 75% have been of island species (Reid & Miller 1989; World Conservation Monitoring Centre 1992), even though island species represent a minority of all species. For example, only 20% of the world's bird species inhabit islands, but 90% of bird species driven to extinction in historic times have been island dwellers (Myers 1979). Higher extinction rates for endemic island species than for nonendemic island populations have been documented for birds generally (Temple 1985), for New Zealand land birds (McDowall 1969), and for reptiles (Case et al. 1992).

Human activities—over-exploitation, habitat destruction, and introduction of species (Reid & Miller 1989; World Conservation Monitoring Centre 1992)—have been the major cause of extinctions on islands over the past 50,000 years (Olson 1989). Introduced diseases may also represent a significant factor (Warner 1968; Diamond 1984*a*; Dobson & May 1986; O'Brien & Evermann 1988; Flesness 1989).

The reason for the susceptibility of island populations to extinction is controversial. The coup de grâce is usu-

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ally delivered by stochastic factors, whether demographic, environmental, catastrophic, or genetic. Pimm (1991) and other ecologists stress the susceptibility of small island populations to demographic and environmental stochasticity, but this susceptibility is predicted on genetic grounds (Frankham 1995*a*). Island populations are expected to suffer an increase in inbreeding because of bottlenecks at foundation and through subsequent low average population sizes. Surprisingly, there has been no evaluation of the role of inbreeding depression in the extinction proneness of island populations.

Inbreeding occurs as a consequence of finite population size. At foundation, an island population's inbreeding coefficient (F) will increase as follows (Falconer & Mackay 1996):

$$\Delta F = \frac{1}{2N_e}, \quad (1)$$

where N_e is the effective number of founders. For example, if a singly inseminated female founds an island population, the inbreeding coefficient in the population increases by 25%. Subsequent to foundation, island populations are typically smaller than their mainland counterparts, resulting in further increases in F (Falconer & Mackay 1996):

$$F = 1 - \left(1 - \frac{1}{2N_e}\right)^t, \quad (2)$$

where t is the number of generations. This implies that endemic island species should be more inbred than nonendemic island species because their time since foundation from a mainland population will typically be greater than that of nonendemic island populations.

Inbreeding reduces reproductive fitness (inbreeding depression) in essentially all naturally outbreeding species where there are adequate data (Wright 1977; Charlesworth & Charlesworth 1987; Ralls et al. 1988; Thornhill 1993; Frankham 1995*a*; Falconer & Mackay 1996). For example, Ralls et al. (1988) found that the progeny of full-sib matings ($F = 25\%$) in captive mammals had 33% higher juvenile mortality than outbred individuals.

Inbreeding increases the risk of extinction (Soulé 1980; Frankham 1995*b*; Newman & Pilson 1997). Frankham (1995*b*) found a marked increase in the risk of extinction beginning at inbreeding coefficients in the intermediate range in deliberately inbred laboratory populations of two species of *Drosophila* and mice, all maintained under benign laboratory conditions. Frankel and Soulé (1981) concluded that between 80% and 95% of deliberately inbred lines were extinct after F exceeded 80%.

In random-mating populations, heterozygosity is expected to be related to the level of inbreeding by the following equation (Rumball et al. 1994):

$$F = 1 - H_t/H_0, \quad (3)$$

where H_t is heterozygosity at generation t. Allozymes variation has been found to accord well with the prediction of this equation in *Drosophila* (Borlase et al. 1993; Woodworth et al. 1994; Woodworth 1996) and in mice (Falconer & Mackay 1996).

Are island populations sufficiently inbred for inbreeding depression to pose an extinction risk? The hypothesis that inbreeding contributes to the extinction proneness of island populations generates three predictions: (1) island populations will have inbreeding coefficients greater than zero; (2) inbreeding coefficients in endemic species will be greater than those in nonendemic species because the former have higher extinction proneness; and (3) inbreeding coefficients in island populations will equal or exceed those for which laboratory species show elevated extinction probabilities. My objective was to evaluate these predictions.

Data Collection and Analyses

A literature review located 193 comparisons of heterozygosities for allozymes or microsatellites between nonendemic island and mainland populations and 38 comparisons of endemic island populations and related mainland species (Frankham 1997); all were populations from oceanic islands. Comparisons encompassed sexually reproducing mammals, birds, reptiles, fish, amphibians, insects, and plants. Effective inbreeding coefficients for each of these island populations (F_e) were estimated by means of the following equation (a derivative of equation 3):

$$F_e = 1 - H_{Is}/H_M, \quad (4)$$

where H_{Is} and H_M are the heterozygosities for island and mainland populations, respectively (Appendices 1 and 2). Data from plant species are included but were omitted from analyses because of uncertainties about breeding systems (equations 3 and 4 do not apply to inbreeding species). The conclusions were not affected by the omission of plants.

Nonparametric tests were used to analyze inbreeding data because ratios are not normally distributed. Wilcoxon signed rank tests were used to determine whether inbreeding coefficients were significantly greater than zero. A Kruskal-Wallis test was used to determine whether inbreeding coefficients in endemic populations exceeded those in nonendemic populations. One-tailed tests were used in all cases for which predictions were directional. Statistical analyses were performed by means of the MINITAB statistical package, version 7.2.

To determine the levels of inbreeding required for extinction risk to be elevated, studies relating inbreeding and extinction in laboratory and domestic animals and plants were located in a literature review and analyzed. Studies were restricted to the 26 cases for which demographic stochasticity was unlikely to be involved because reserve matings were used or for which there were four or more matings per generation (Table 1). Most inbreeding studies use reserve matings to minimize extinctions. For example, full-sib inbreeding is typically done by mating a brother and a sister and setting up one or more additional full-sib matings that are discarded if the first produces progeny. If the first mating fails, the second is used to continue the line, and so forth. The use of spares also minimizes the impact of demographic stochasticity. For example, the natural frequency of mating failures in such a captive outbred population is typically 5–10%, so the use of a single reserve under full-sib mating reduces the risk of losing a line to 0.25–1% per generation in the absence of inbreeding depression. Frankham (1995*b*) showed that demographic stochasticity was an extremely minor factor for the data sets of Bowman and Falconer (1960), Kosuda (1972), and Rumball et al. (1994), for which spares were used. For captive populations with sizes larger than four, extinctions due to demographic stochasticity have a frequency of about 0.1^4 per generation or less and so can be ignored. Studies in which there was deliberate selection for high reproductive fitness during inbreeding were excluded.

Results

For both endemic and nonendemic island populations, the inbreeding coefficients were significantly different from zero (Fig 1; Wilcoxon statistics 398.0, $p < 0.0005$, and 14,497.0, $p < 0.0005$). Inbreeding coefficients were significantly higher in endemic than nonendemic island populations (Kruskal-Wallis $H = 11.96$, df = 1, $p = 0.0005$). The mean F_e for nonendemic populations was 0.29 (median 0.28), and 29% of populations had an F_e in excess of 0.50. For endemic species the mean F_e was 0.57 (median 0.63), and F_e exceeded 0.50 in 64% of populations.

There was a highly significant decline in the percentage of populations surviving with increasing inbreeding coefficient in deliberately inbred populations of laboratory and domestic animals (Fig. 2), the best-fitting weighted regression being percentage of surviving populations

Table 1. Extinction rates of inbred lines (extinct %) of domestic and laboratory species, levels of inbreeding (F), population size during inbreeding, number of replicates, and references.[a]

Species	Population size	F	Extinct (%)	No. of replicates	Reference
Mammals					
Cavia porcellus	2	0.94	35	23	Wright 1922
Mus musculus	2	0.99	95	20	Bowman & Falconer 1960
	2	0.83	69	13	Lorenc 1980
	2	0.95	88	16	Eisen & Hanrahan 1974
	4	0.76	50	8	Eisen & Hanrahan 1974
	8	0.42	0	4	Eisen & Hanrahan 1974
	32	0.12	0	2	Eisen & Hanrahan 1974
wild	2	0.73	80	10	Lynch 1977
	2	0.99	50	10	Connor & Bellucci 1979
Mustela vison	2	0.50	94	17	Johansson 1961
Birds					
Coturnix coturnix	2	0.67	65	17	Kulenkamp et al. 1973
Gallus domesticus	2	0.96	97	279	Abplanalp 1974
Meleagris gallopava	2	0.50	80	15	Abplanalp & Woodard 1967
	2	0.38	20	15	Abplanalp & Woodard 1967
Phasianus colchicus	2[b]	0.47	60	10	Woodard et al. 1983
Insects					
Drosophila melanogaster	2	0.99	50	10	Clayton et al. 1957
	2	0.78	25	20	Frankham et al. 1993
	2	0.98	77	120	Rumball et al. 1994
	2	0.91	81	78	Rumball et al. 1994
	4	0.78	44	60	Rumball et al. 1994
	67	0.69[c]	25	60	Latter et al. 1995
Drosophila virillis	2	0.73	33	117	Kosuda 1972
Tribolium castaneum	2	0.89	80	84	Wool & Bergerson 1986
	2	0.89	92[d]	84	Wool & Bergerson 1986
	2	0.86	36	50	Wool & Sverdlov 1976
Plants					
Lolium multiflorum	1	0.88	95	20	Polans & Allard 1989

[a] *All studies used reserve matings or were of a size at which demographic stochasticity was unlikely to be important.*
[b] *Backcrossed to a single parent.*
[c] *Effective inbreeding coefficient from allozyme data.*
[d] *Inbreeding carried out under deleterious variable environmental conditions (omitted from statistical analyses reported in the text).*

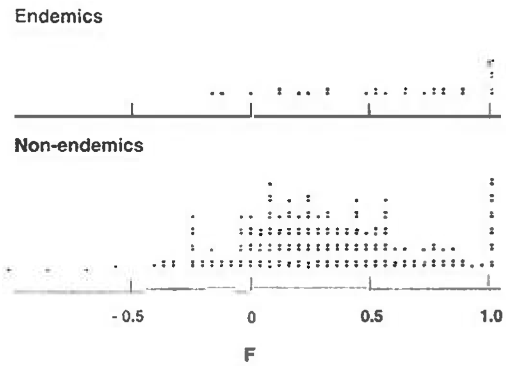

Figure 1. Distribution of inbreeding coefficients in endemic and nonendemic populations on islands. Both island and mainland populations are significantly inbred, with endemic island populations more inbred than nonendemic ones.

equal to 64.3-62.8 F^6. The relationship is consistent with a threshold for extinctions beginning at intermediate levels of F, as found within populations by Frankham (1995*b*). The weighted mean extinction rate of the studies in Table 1 was 68%, and the corresponding inbreeding coefficient was 0.85. Of 26 cases, 24 showed extinctions, as did all cases with $F > 0.5$. There was no significant difference in extinction rates among mammals, birds, invertebrates, and plants.

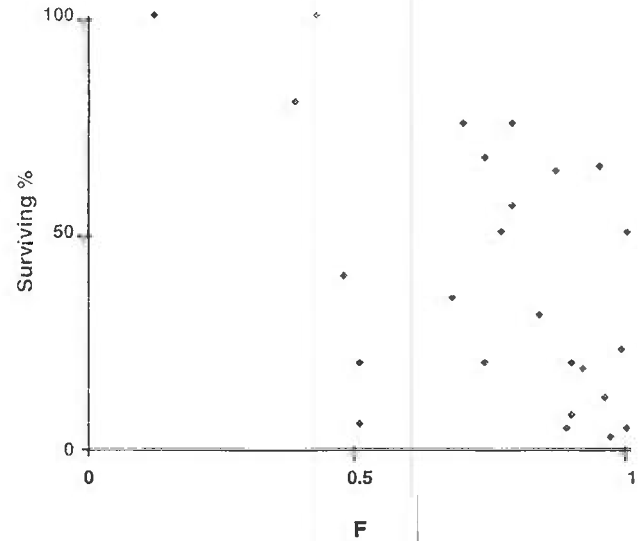

Figure 2. Relationship between percentage of populations surviving and inbreeding coefficient in deliberately inbred captive populations of animals and plants. There is a significant curvilinear relationship.

Discussion

This study has established that both endemic and nonendemic island populations are significantly inbred and that endemic island populations are more inbred than nonendemic populations. Furthermore, many island populations have inbreeding coefficients in the range where laboratory and domestic animals suffer elevated extinction rates. These results confirm each of the predictions of the hypothesis that inbreeding contributes to the extinction proneness of island populations.

The comparison of endemic and nonendemic island populations is particularly informative. Endemic island populations have higher extinction rates than nonendemic island populations (McDowall 1969; Temple 1985; Case et al. 1992). Because there is no obvious ecological reason to expect endemic island species to be more prone to habitat destruction or to environmental or demographic stochasticity than nonendemic island species, genetic factors (inbreeding depression, loss of genetic variation, or genetic adaptation to island conditions) or their interactions with demographic or environmental stochasticity are probably involved in the difference in extinction proneness.

Chance, high migration rates, and separate migrations from differentiated mainland populations can all cause some values of F_e to be negative. Many such cases are associated with high dispersal ability, including *Macrotus waterhousii*, *Mus musculus*, and *Rattus rattus*, with *Mus* having several differentiated subspecies (Frankham 1997).

Island populations show evidence that may indicate inbreeding depression: island plants frequently have low germination rates, whereas insular birds and lizards often have small clutch sizes (Carlquist 1974; Williamson 1981; World Conservation Monitoring Centre 1992), although inbreeding depression is not the only possible reason.

Inbreeding coefficients in many island populations reach levels associated with high risks of extinction in deliberately inbred populations of laboratory and domestic animals. There are three factors that differ between the effects of inbreeding in island populations and those of captive species: rate of inbreeding, severity of environmental conditions, and the use of F values from pedigrees versus those estimated from genetic markers. The first may exaggerate the extinction risk for island populations compared to laboratory populations, whereas the latter two will lead to its being underestimated.

Inbreeding in the laboratory populations is generally faster than in island populations. For the same F, slower inbreeding is generally less deleterious than faster inbreeding (Tantawy & Reeve 1956; Cornelius & Dudley 1974; Good & Hallauer 1977; Ehiobu et al. 1989; Latter et al. 1995; Falconer & Mackay 1996). But no significant effects of rate of inbreeding on extinction risk for the same total inbreeding have been found in either a study in which inbred lines came from a single *Drosophila* population (Frankham 1995*b*) or in a meta-analysis of the populations described in Table 1 (Frankham, unpublished data). Consequently, the effects of the rate of inbreeding on extinction risk do not appear to be large. Further, oceanic island populations will often suffer a rapid increase in inbreeding at foundation. Those populations founded from a singly inseminated female suffer an increase of 25% in inbreeding coefficient. Founder bottlenecks are likely on oceanic islands but not on landbridge islands.

Environmental conditions on islands will generally be harsher and more variable than in the laboratory. Because inbreeding depression is typically more severe in harsh than benign conditions (Hoffmann & Parsons 1991; Chen 1993; Jimenez et al. 1994; Keller et al. 1994; Latter et al. 1995), it will be greater in island than captive populations for the same *F*. Island populations of Galapagos finches (Weiner 1994), sparrows (Keller et al. 1994), Laysan Ducks (Cooper et al. 1996), and lizards (Quammen 1996) suffer high mortality due to environmental extremes. Extinction rates due to inbreeding have been shown to be greater under harsher and more variable environmental conditions than under typical benign captive conditions (Table 1; Wool & Bergerson 1986).

Do inbreeding coefficients determined from pedigrees agree with those estimated using genetic markers? Pedigree inbreeding coefficients and effective inbreeding coefficients estimated from allozyme heterozygosities in the same populations show close agreement in finite populations under conditions of variable versus equalized family sizes and fluctuating versus stable population size in *Drosophila* (Borlase et al. 1993; Woodworth et al 1994) and in mice (Falconer & Mackay 1996). In particular, Woodworth (1996) found excellent agreement with the prediction of equation 3, based on changes in allozyme heterozygosity in 23 pedigreed populations of *Drosophila melanogaster* maintained for 24 generations at effective sizes ranging from 25 to 500. In rapidly inbred lines, effective inbreeding coefficients are somewhat lower than pedigree inbreeding coefficients (Mina et al. 1991; Rumball et al. 1994), to about 20% lower than pedigree *F* values in lines inbred using full-sib and double-first-cousin matings in the study (by Rumball et al. 1994). Consequently, the island populations I analyzed will generally be more homozygous for the same *F* than rapidly inbred laboratory and domestic animals. Overall, it seems unlikely that wild populations on islands will be any less susceptible to inbreeding-induced extinctions than are captive populations for the same levels of inbreeding.

Inbreeding depression, loss of genetic variation, accumulation of mildly deleterious mutations ("mutational meltdown"), and genetic adaptations to island environments can all contribute to higher extinction rates in island than in mainland populations. Genetic adaptations to island environments (e.g., loss of dispersal ability, limited ability to avoid predators, and lower resistance to diseases) are widely acknowledged as a reason for the extinction proneness of island endemic species (Carlquist 1974; Myers 1979; Soulé 1983; Temple 1985; Vitousek 1988; Atkinson 1989; World Conservation Monitoring Centre 1992; Cody & Overton 1996). A test for mutational meltdown has not confirmed it as a threat to finite sexual populations over 45–50 generations (Gilligan et al. 1997). Island populations have lower average levels of genetic variation than mainland populations (Frankham 1997). The evidence herein shows that insular populations, especially endemic species, have elevated inbreeding coefficients and so are expected to suffer from inbreeding depression. These genetic threats to island populations will interact with demographic and environmental stochasticity and catastrophes to increase the risk of extinction of island populations.

In conclusion, island populations are significantly inbred and endemic populations more so than nonendemic ones. Island populations are often inbred to levels associated with elevated extinction risks in laboratory and domestic species. Inbreeding cannot be excluded as a cause of the extinction proneness of island populations.

Conservation Implications

Endangered island species may be more difficult to conserve than endangered mainland species because of their higher inbreeding levels. They may often be more susceptible to stress and disease than mainland populations and so may need extra care. Further, island populations may have lower reproductive fitness than related mainland populations and so may be less suitable for reintroductions. Habitat fragmentation is likely to increase extinction proneness due to inbreeding because small, isolated populations will become inbred over time. Where possible, exchange of immigrants among isolated populations of the same species should reduce extinction risks from inbreeding.

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Appendix 1

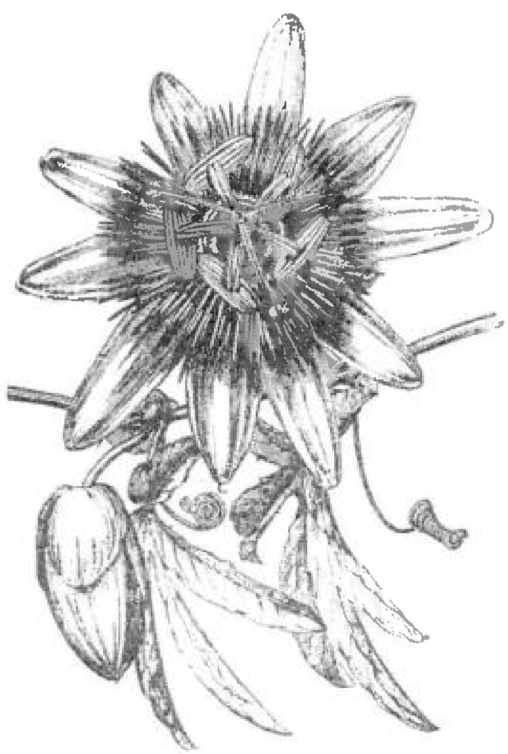
Effective inbreeding coefficients (F_e) in nonendemic island populations.

Species	F_e	*Reference*
Mammals		
Canis lupus	0.552	Wayne et al. 1991*b*
Lemur macaco	0.518	Arnaud et al. 1992
Macaca fascicularis	0.214, 0.224, 0.748, 0.708, 0.406, 0.486, 0.516	Kondo et al. 1993
Macaca fuscata	1.000, −0.574	Nozawa et al. 1975
Macaca fuscata	0.802	Nozawa et al. 1991
Macrotus waterhousii	−0.128	Greenbaum & Baker 1976
Mastomys erytholeucus	0.634	Duplantier et al. 1990
Mastomys huberti	0.590	Duplantier et al. 1990
Mus musculus	0.198, 1.000, 1.000, −0.210, 0.456, 0.315, 0.597, 0.946, 0.281, 0.462, 0.234, 0.288, 0.812, 1.000, 0.839, −0.048, 0.651, 0.866, 0.126	Berry & Peters 1997
Mus musculus	−0.035	Berry et al. 1978
Mus musculus	0.543	Berry et al. 1979
Mus musculus	−1.012, −0.382, −0.321	Berry et al. 1981
Mus musculus domesticus	−0.250, 0.091, −0.250, −0.250, 0.318	Navajas y Navarro & Britton-Davidian 1989
Panthera pardus	0.548	Miththapala et al. 1991
Peromyscus eremicus	0.445, 0.899	Avise et al. 1974*a*
Peromyscus gossypinus	−0.162, −0.172, 0.101, −0.071, 0.071, 0.212	Boone et al. 1993
Peromyscus leucopus	0.025, 0.350, 0.075	Browne 1977
Peromyscus maniculatus	0.289, 0.253, 0.048, −0.205, 0.386, 0.036, 0.422, 0.434	Gill 1980
Peromyscus maniculatus	1.000, 0.427, 0.396, 0.469, 0.312, 0.750	Aquadro & Kilpatrick 1981
Peromyscus polionotus	0.002, 0.523	Selander et al. 1971, Garten 1976, Brewer et al. 1990
Rattus fuscipes	1.000, 1.000, 1.000, 0.434, 1.000, 0.245, 1.000, 1.000, 1.000, 0.434	Schmitt 1978
Rattus rattus	0.065, 0.742, 0.258, −0.226, 0.019, 0.710, −0.355, −0.258	Patton et al. 1975
Sigmodon hispidus	0.036	Johnson & Selander 1972
Sorex cinereus	0.468, 0.582, −0.241, 0.418, 0.203	Stewart & Baker 1992
Spermophilus spilosoma	0.900	Cothran et al. 1977
Ursus americanus	0.545	Paetkau & Strobeck 1994
Birds		
Aplonis cantoroides	0.833, 0.833, 0.231	Corbin et al. 1974
Aplonis metallica	0.440, 0.073, 0.275, 0.018, −0.034	Corbin et al. 1974
Callipepla californica	0.272	Zink et al. 1987
Empidonax difficilis	0.387	Johnson & Marten 1988
Fringilla coelebs	−0.011, −0.011, 0.103, −0.107, −0.048, −0.164, 0.179, 0.084, 0.332, 0.447, 0.504, 0.198, 0.408, 0.676	Baker et al. 1990
Lagopus lagopus	0.062, 0.225, 0.125	Gyllensten et al. 1985
Reptiles		
Anolis carolinensis	−0.053	Webster et al. 1972
Lacerta sicula	0.375, 0.675, 0.474, 0.514	Gorman et al. 1975
Trachydosaurus rugosus	0.249, 0.311, 0.311, 0.255, 0.187, 0.280, 0.069	Sarre et al. 1990
Uta stansburiana	−0.843, −0.335, 0.511, 0.737, 0.041, 0.323, 0.379, 0.549, 0.097, 0.568, 0.144, −0.034, −0.674, −0.373	Soulé & Yang 1973, McKinney et al. 1972

continued

Appendix 1 (continued)

Species	F_e	*Reference*
Amphibian		
Bufo viridis	0.782	Dessauer et al. 1975
Bufo woodhousii fowleri	0.636	Hranitz et al. 1993
Molluscs		
Cerion bendalli	0.114, 0.118	Woodruff 1975
Insects		
Drosophila equinoxialis caribbensis	0.288, 0.212, 0.153, 0.342, 0.158	Ayala et al. 1974
Drosophila immigrans	−0.237	Steiner et al. 1976
Drosophila nebulosa	0.096	Powell 1975
Drosophila simulans	0.549, 0.549	Steiner et al. 1976
Drosophila subobscura	0.171, −0.048, 0.355, 0.174, 0.310	Cabrera et al. 1980
Drosophila tropicalis	0.157	Powell 1975
Drosophila willistoni	0.150, 0.226, 0.123, −0.003, 0.172, 0.046	Ayala et al. 1971
Philaenus spumarius	0.094, −0.064, 0.007, 0.543, 0.356, 0.760	Saura et al. 1973
Plants		
Atherosperma moschatum	0.070, 0.105	Shapcott 1994
Campanula punctata	0.889, 0.821, 0.923, 0.581, 0.556, 0.047	Inoue & Kawahara 1990
Eichhornia paniculata	0.667	Glover & Barrett 1987
Quercus petraea	−0.047	Zanetto & Kremer 1995
Turnera ulmifolia	0.667	Barrett & Husband 1989



Appendix 2

Effective inbreeding coefficients (F_e) in endemic island populations.*

Island Species	F_e	*Reference*
Mammals		
Dipodomys compactus	0.706	Johnson & Selander 1971
Macaca fuscata	0.574	Nozawa et al. 1991
Microtus breweri	0.890	Kohn & Tamarin 1978
Peromyscus eva	1.000	Avise et al. 1974*a*
Peromyscus diskeyi	1.000	Avise et al. 1974*a*
Peromyscus guardia	0.533	Avise et al. 1974*a*
Peromyscus interparietalis	1.000	Avise et al. 1974*a*
Peromyscus sejugis	0.790	Avise et al. 1974*a*, 1979, Selander et al. 1971, Kilpatrick 1981
Peromyscus stephani	1.000	Avise et al. 1974*a*, 1974*b*, Kilpatrick & Zimmerman 1975
Urocyon littoralis	0.799	Wayne et al. 1991*a*
Birds		
Hemignathus parvus	0.748	Johnson et al. 1989
Hemignathus virens	0.135	Johnson et al. 1989
Himatione sanguinea	0.634	Johnson et al. 1989
Loxioides bailleui	1.000	Johnson et al. 1989
Loxops coccineus	1.000	Johnson et al. 1989
Oreomystis bairdi	0.495	Johnson et al. 1989
Paroreomyza montana	0.117	Johnson et al. 1989
Telespiza cantans	0.874	Johnson et al. 1989
Vestiaria coccinea	0.631	Johnson et al. 1989
Insects		
Drosophila adiostola	0.307	Ayala 1975, Powell 1975
Drosophila crassifemur	−0.004	Ayala 1975, Powell 1975
Drosophila dolichotarisi	0.317	Ayala 1975, Powell 1975
Drosophila nigella	0.258	Ayala 1975, Powell 1975
Drosophila nigra	0.208	Ayala 1975, Powell 1975
Drosophila planitibia	−0.168	Ayala 1975, Powell 1975
Drosophila sechellia	0.769	Cariou et al. 1990
Drosophila truncipenna	−0.108	Ayala 1975, Powell 1975
Arachnids		
Steganacarus (S.) tenerifensis	0.527	Avanzati et al. 1994
Plants		
Crepidiastrum ameristophyllum	0.380	Ito & Ono 1990
Crepidiastrum grandicollum	0.753	Ito & Ono 1990
Crepidiastrum linguaefolium	0.758	Ito & Ono 1990
Galvezia leucantha	0.836	Elisens 1992
Gossypium darwinii	0.515	Wendel & Percy 1990, Percy & Wendel 1990
Gossypium klotzschianum	0.604	Wendel & Percival 1990
Gossypium tomentosum	0.694	DeJoode & Wendel 1992, Wendel et al. 1992
Hosta jonesii	−0.784	Chung 1994
Rhaphithamnus venustus	0.728	Crawford et al. 1993
Solanum fernandezianum	1.000	Spooner et al. 1992

**Nearest mainland relatives are given in Frankham (1997*a*).*

HEDRICK ET AL-1996-CONSERVATION BIOLOGY (1)

Directions in Conservation Biology: Comments on Caughley

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Abstract: *The recent review by Caughley (1994) on approaches used in conservation biology suggested that there are two: the small population paradigm and the declining population paradigm. We believe that this division is overly simplistic and that it should not be perpetuated. Both the deterministic factors that reduce population size and the stochastic factors that lead to the final extinction of a small population are critical to consider in preventing extinction. Only through an overall and comprehensive effort, which we call inclusive population viability analysis, can extinction processes be understood and mitigated. In this context we discuss Caughley's comments about genetics, demography, and general population viability, with particular attention to cheetahs* (Acinonyx jubatus) *and Pacific salmon* (Oncorhynchus *sp.*).

Direcciones en la biología de la conservación: Comentarios sobre Caughley

Resumen: *La revisión reciente hecha por Caughley (1994) sobre aproximaciones en la biología de la conservacion sugiere que existen dos de ellas: El paradigma de la población pequeña y el paradigma de la población en disminución. Sentimos que esta división es demasiado simplista y no debería ser perpetuada. Tanto los factores determinísticos que reducen el tamaño poblacional, como los factores estocásticos que conducen a la extinción de una población pequeña son críticos en la prevención de su extinción. Unicamente a través de un esfuerzo general y comprensivo, que incluso llamaríamos análisis de viabilidad poblacional, se podrán entender los procesos de extinción y ser mitigados. En éste contexto, discutimos los comentarios hechos por Caughley sobre genética, demografía y viabilidad poblacional general con particular atención en los chitas* (Acinonyx jubatus) *y el salmón del Pacífico* (Oncorhynchus *sp.*)

Introduction

Just before he died, Caughley (1994) wrote a provocative review outlining his perspective of the scientific approaches used in conservation biology (see also Caughley & Gunn 1995). His essay, as probably intended, has generated substantial controversy and resulted in the questioning of some of the tenets presently used in conservation biology research. Although it is useful to evaluate the accomplishments and problems in a discipline, we feel that Caughley constructed a false dichotomy between what he calls the "small population paradigm" and the "declining population paradigm." His review also contained a number of misunderstandings about the application of ideas from the demography and genetics of small populations to conservation biology. This potentially divisive separation of approaches unfortunately comes when a number of new molecular genetic techniques promise exciting and detailed understanding of the genetics and evolution of populations and species and when new, spatially-explicit computer models promise greater understanding of habitat fragmentation and metapopulation dynamics.

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An arbitrary separation of approaches as delineated by Caughley may unprofitably polarize conservation biologists and result in pitting different approaches against each other when hostile political forces are attempting to discredit many conservation efforts. Contrary to Caughley's view, it appears to us that in recent years there has been greater emphasis on and more success in integrating natural-history information for particular endangered species into a general theoretical context, an effort that appears to be supported by both the more applied and the more theoretical conservation biologists. For example, efforts in this direction have been made by the Conservation Breeding Specialist Group of The World Conservation Union (IUCN) to include habitat considerations into their population viability analyses. We applaud the successes of the scientific approaches described by Caughley in identifying the factors causing population or species declines, and we urge their general application, a tradition in conservation biology (Myers 1987). We recognize that it is critical to identify and mitigate the factors in the decline of a species (Long et al. 1995). As conservation biologists, we should always remember that our motivation is not to win a debate or to demonstrate the correctness of a given approach but to use all methods at our disposal to maintain the integrity of natural ecosystems and stem the loss of biodiversity.

We discuss some more conclusions of Caughley (1994), and we give what we hope is a constructive perspective on his commentary. We then discuss Pacific salmon, (*Oncorhynchus* sp.) a species that could have benefited greatly from the integration of Caughley's polar paradigms, and the cheetah, (*Acinonyx jubatus*) genetic studies of which have been a main subject of recent criticism, including that of Caughley. Finally, we discuss a melding of the paradigms into an "inclusive population viability analysis" and try to encourage a profitable synergism among conservation biologists with different viewpoints, as Caughley himself was apparently attempting.

Perspective

Caughley (1994) suggested that there are two basic approaches to understanding the factors influencing extinction. First, he suggested that the small-population paradigm endeavors to determine "the effects of smallness on the persistence of a population" and deals with "the risk of extinction inherent in low numbers." Second, he states that the declining population paradigm deals with "the cause of smallness and its cure" and "with processes by which populations become extinct." As he summarizes, the factors causing extinction under the small-population paradigm are environmental stochasticity and catastrophes, demographic stochasticity, and genetic deterioration (Frankel & Soulé 1981; Shaffer 1981, 1987; Lande 1988*a*; Lande 1993), whereas under the declining population paradigm the factors causing extinction are overkill, habitat destruction and fragmentation, impact of introduced species, and chains of extinction (Diamond 1984, 1989).

We believe that this separation is artificial. In general, the factors under the small-population paradigm are the stochastic ones that may result in the proximate cause of extinction, and the ones under the declining population paradigm are the deterministic (or ultimate) ones that reduce the population size so that it becomes vulnerable to random events and phenomena. As suggested by Shaffer (1981), the concern over stochastic factors arose precisely because of the realization that, even with adequate natural habitat and species protection, and even with a positive mean population growth rate, random factors may cause a species with low numbers to become more vulnerable or extinct. Researchers attempting to understand the proximate causes of extinction have always known that without removal of the deterministic driving forces, such as loss of habitat, introduced predators, and pollution, the population or species will inevitably go extinct.

Further, once deterministic factors have led to small, fragmented, and isolated populations, stochastic factors may further reduce numbers, and the interaction of forces may contribute to further endangerment, as illustrated by the extinction vortices of Gilpin and Soulé (1986). We think it more productive and accurate to cast the discussion in terms of an analysis of viability that considers both the generally anthropogenic ultimate causes and the stochastic proximate causes—an inclusive population viability analysis. We consider characteristics of population viability analysis (PVA) that are crucial to this inclusive approach.

Genetic Factors

Caughley (1994) acknowledged that genetic considerations in avoiding inbreeding and maximizing retention of genetic variation have played a major role in captive breeding. Insufficient attention to small-population threats has resulted in damaging losses of viability and fecundity in many—now inbred—captive stocks (Ralls & Ballou 1983; Ralls et al. 1988; Lacy et al. 1993). Prior to the work of Ralls and Ballou, zoo curators rarely acknowledged that inbreeding might contribute to the rapid deterioration in vigor and fitness of small, captive groups.

In addition, genetics has made an important contribution to understanding threats facing natural populations. Loss of genetic diversity in small populations has apparently reduced fitness in natural populations of plants (Bijlsma et al. 1994), topminnows (*Poeciliopsis occidentalis*; Vrijenhoek 1994), wolves (*Canis lupus*; Wayne et al. 1991), African lions (*Panthera leo*; Packer et al. 1991), and Florida panthers (*Felis concolor coryi*; Roelke et al. 1993). But perhaps the most important contributions of genetic information to conservation have been its general utility in the identification of species, understanding the structure and differentiation of populations, describing the mating or reproductive system, or determining other evolutionary, ecological, or behavioral information unrelated to selective differences.

Demographic Factors and Stochasticity

Small-population models have also forced us to reexamine some of the methodologies of demographic analysis that are well entrenched in wildlife ecology and management. For example, standard life-table analyses on long-term average birth and death rates will systematically underestimate the rates of population decline when vital rates vary over time or space (Tuljapurkar & Orzak 1980; Goodman 1987; Beissinger 1995). Caughley identifies the use of maximum-sustained-yield models to prevent extinction by overkill as one of the "areas of theory to which the declining-population paradigm can lay claim." But harvesting strategies based on models that neglect the possibility of extinction have been found to provide lower mean annual yields and to subject populations to greater risk of extinction than do optimal harvesting strategies that take into consideration that demographic and environmental stochasticity can lead to extinction (Lande et al. 1995). Thus, determination of optimal harvesting strategies that do not jeopardize both yield and population persistence requires the joint application of declining-population and small-population theories. Similarly, the risk that economic weighing of the value of a sustained resource against the discount rate will lead to deliberate harvest to extinction is altered by the inclusion of stochastic processes in the models (Lande et al. 1994). That stochastic processes by themselves, or in interaction with deterministic factors, are of more than theoretical interest is demonstrated by the collapse of many managed fisheries (Ludwig et al. 1993), the loss to disease of the last wild population of black-footed ferrets (*Mustela nigripes;* Clark 1989; Seal et al. 1989), and the decimation and subsequent extirpation of the last nonmigratory population of whooping cranes (*Grus americana*) as a result of a hurricane (Doughty 1989).

Synthesis of Factors in a PVA Approach

Caughley suggests that the strengths of small-population models include their theoretical underpinnings and potential for generality across species. We agree that these are positive and appealing aspects that have allowed testing of the underlying hypotheses of these models and resulted in both extensive investigation of its theoretical constructs and experimental examination of them. Further, small-population models may be attractive because the theory can be mathematically elegant (or at least mathematically well-defined). But models are important for more than their aesthetic qualities. For decades there has been discussion about declining populations, but without models or theory that would allow precise description or prediction. A strong advantage of many of the small-population models is that they can be subjected to testing by examination of the properties of the models and assumptions (Taylor 1995), by comparison of the fit of the model results to data on past population dynamics (Mirande et al. 1991), and by comparison of predictions for the future to monitored performance. In addition, they can be used to determine what other population information is necessary to predict population trends more accurately.

Substantial experimental research has been conducted to determine the general validity of small-population models. Laboratory research has generally supported its genetic assumptions (Frankham 1995) and has further demonstrated, for example, that all fitness components can be influenced by inbreeding (Miller & Hedrick 1993), that inbreeding depression may by somewhat greater in stressful environments (Dudash 1990; Wolfe 1993; Miller 1994) and that inbreeding may result in lowered fitness in natural environments (Jiménez et al. 1994; Keller et al. 1994). This is not to say that there are no unresolved issues, such as the impact of bottlenecks on genetic variation and the association of genetic variation, fitness, and extinction (Hedrick & Miller 1992).

The Florida panther is a case that exemplifies how the quantitative nature of small-population models helps drive analysis of data, which in turn provides guidance to conservation efforts. Intensive field research provided a record of most of the deaths that occurred during the past decade. Yet there had not been a detailed examination of the mean mortality rate and the variation in mortality across years, until such was required by the application of PVA models to conservation planning. Analysis of the data and population projections with PVA modeling revealed that the panthers are extremely vulnerable to small-population problems, such as inbreeding and an absence of mates for some animals because of the locally variable sex ratios of breeders. Accordingly, conservation efforts for Florida panthers now include the restoration of genetic variation and supplementation of the breeding population through augmentation from the Texas population of the species (Seal 1992,1994; Hedrick 1995).

In the case of the Whooping Crane, even more-detailed data on mortality and reproduction were available: a tally of recruitment and deaths had been recorded every year since 1938. A PVA built upon the earlier deterministic models of population growth (Binkley & Miller 1983; Boyce 1987) and incorporated stochastic processes that could destabilize even a growing population

(Mirande et al. 1991). When applied to the population status as it existed in 1938, the PVA model accurately projected population growth and the magnitude of fluctuations over the subsequent 52 years. The analyses indicated that Whooping Cranes are now at large enough numbers that the threats of inbreeding and demographic stochasticity are declining; the primary threat remaining is the possibility of local catastrophic loss of the sole remaining population due to disease or other factors (Mirande et al. 1991). This risk, which could not have been evaluated in a wholly deterministic analysis, is being addressed through the establishment of a nonmigratory population of Whooping Cranes in Florida.

The interaction of demographic and environmental factors also affects small populations. For example, the last five Dusky Seaside Sparrows (*Ammodrumus maritimus nigrescens*) were males, an improbable, stochastic event that effectively terminated the taxon. Similarly, the last Illinois population of lakeside daisy (*Hymenoxys acaulis* var. *glabra*) was all of the same self-incompatible mating type (DeMauro 1993). Rare plants (Karron 1987) and those in small populations (Widen 1993) can suffer reduced seed set due to lack of pollinators. Other vital rates are also affected by stochastic processes acting on local populations of plants (Schemske et al. 1994). Small, local populations of animals have been found to be more likely to go extinct (Soulé et al. 1988; Berger 1990; Rosenzweig & Clark 1994; Hanski et al. 1995; Newmark 1995). An unusually dry year in a Costa Rican cloud forest apparently caused the extinction of the golden toad (*Bufo periglenes*) and the local extirpation of the harlequin frog (*Atelopus varius*) (Pounds & Crump 1994).

Caughley suggests that consideration of the effects of small populations has not significantly contributed to preventing extinctions. Given the high profile of the Spotted Owl (*Strix occidentalis caurina*) controversy (see Harrison et al. 1993 and references therein), it is hard to understand Caughley's statement that he "can find no example of the idea of minimum viable population size being applied" to species conservation. Further, several studies have demonstrated that excessive emphasis on the obvious deterministic factors can be misleading, resulting in conclusions that are too optimistic about viability and persistence. For example, it was generally accepted for many years that predation by Common Ravens (*Corvus corax*) on young desert tortoises (*Gopherus agassizii*) was the major factor jeopardizing their survival in some parts of the southwest. A PVA showed, however, that the most sensitive stage by far were mature females, and an emphasis on reducing raven predation erred in mistaking a highly visible impact for a demographically significant one (Doak et al. 1994). Work on loggerhead sea turtles (*Caretta caretta*) has similarly shown the difficulty in guessing the relative significance of different vital rates in determining population growth (Crouse et al. 1987). Thus, one cannot always interpret the significance of deterministic factors unless a proper inclusive PVA is carried out.

Caughley further states that no "instance of extinction by genetic malfunction has been reported." Although the strength of the evidence can be disputed, several studies have reported extinctions caused—in the end—by "genetic malfunctions" (e.g., Heath Hens [*Tympanchus cupido cupido*; Simberloff 1988] and the Swedish population of Middle Spotted Woodpeckers [*Dendrocapus medius*; Pettersson 1985]. More important, Caughley's assertion illustrates a basic misunderstanding of the impact of genetics on extinction. Genetics does not operate in isolation but will influence a population through its effects on disease resistance, viability, reproductive success, behavior, physiology,and other characteristics. For example, in zoo animals inbred individuals often die from a variety of medical problems, whereas mortality in outbred animals is more likely from accidents (Ralls et al. 1980).

Disagreement over whether or not genetics should be considered in demographic predictions of population persistence has been unfortunate and misleading. Extinction is a demographic process that is likely to be influenced by genetic effects under some circumstances. The important issue is to determine under what conditions genetic concerns are likely to influence population persistence (Nunney & Campbell 1993; Mills & Smouse 1994). For example, lethal or even sublethal alleles may be purged in small populations, but slightly deleterious variants may become fixed and thereby lower viability and mating success (Hedrick 1994). Lande (1988*a*), who emphasized the importance of demographic factors over genetic ones in causing extinction, has recently suggested (Lande 1995) that the population size necessary to maintain genetic variation is an order of magnitude higher than previously thought, which places greater emphasis on genetic factors. Further, recent theoretical work suggests that the fixation of new mutants with slightly detrimental effects may lead to a long-term decline in population fitness and to eventual extinction (Lynch et al. 1995).

Perhaps most important, we need to recognize when management recommendations based upon strictly demographic or genetic considerations may actually conflict with each other. For example, Ryman and Laikre (1991) have considered supportive breeding in which a portion of wild parents are brought into captivity for reproduction and their offspring are released into the natural habitat, where they mix with wild conspecifics. Programs similar to this are carried out in a number of species to increase population size and thereby temper stochastic demographic effects. But under some circumstances, supportive breeding may reduce effective population size and cause a drastic reduction in genetic variation (Ryman & Laikre 1991; Ryman et al. 1995; but see Hedrick et al. 1995).

Case Studies

There are number of species for which small population considerations are of great significance. We discuss cheetahs, because of the detailed commentary by Caughley, and Pacific salmon, because of the special relevance of small-population theory to their survival.

Cheetah

The conservation biology history of the cheetah developed by O'Brien (O'Brien et al. 1983, 1985) has been the focus of extensive recent controversy among Caughley (1994) and others (Caro & Laurenson 1994; Merola 1994). We discuss it to point out the misrepresentations and misinterpretations of these data. Although we do not completely agree with Caughley, we believe that a more balanced evaluation of these data based on evolutionary genetics is necessary to achieve a more integrated assessment of the cheetah's vulnerability.

The examination of molecular genetic variation in the cheetah is probably the most extensive of any endangered species and includes estimates of variation in allozymes, soluble proteins, major histocompatibility genes (from both restriction fragment length polymorphisms [RFLPs] and tissue transplants), mitochondrial DNA, minisatellites, and microsatellites. For allozymes in particular, the extent of variation is low in cheetahs, where as for mtDNA, minisatellites, and microsatellites, the extent of variation is nearly as high as in other big cats (Menotti-Raymond & O'Brien 1993, 1995). The initial findings of low allozyme variation in the cheetah led to the conclusion that the cheetah is vulnerable to extinction because of its lack of genetic variation. But the equilibrium genetic variation among species is expected to vary, largely because of differences in long-term effective population size. A species with low genetic variation does not necessarily suffer a decrease in fitness. Caughley provides a brief discussion of why a simple relationship between heterozygosity and vulnerability to extinction is unlikely (see also Hedrick et al. 1986).

On the other hand, low genetic variation in a species may be indicative of a recent population bottleneck, and there are several reasons to expect that such a bottleneck does potentially indicate vulnerability to extinction. First, a recent bottleneck may indicate demographic instability that is not obvious from contemporary population size alone. Second, a species that has gone through a bottleneck severe enough to erode detectable molecular genetic variation may suffer from fixation of detrimental alleles with the consequent lowered fitness that may increase vulnerability to extinction. Finally, loss of genetic variation caused by the bottleneck may limit the ability of the population to evolve and adapt. The more recent a bottleneck has been, the more we would expect the bottleneck to influence the future of a species.

The low allozyme variation in cheetahs may actually indicate past history, either because of one or more bottlenecks or because of a chronically low effective population size due to, for example, metapopulation dynamics (Gilpin 1991; Hedrick 1996). The higher variation for mtDNA, minisatellites, and microsatellites may also be expected because of the higher mutation rates for these genes (Menotti-Raymond & O'Brien 1993, 1995). In fact, these molecular methods and others available today (Smith & Wayne 1996) may eventually allow us to gain some understanding of the previous history of cheetahs (Hedrick 1996). There does appear to be variation in genes influencing fitness, because evidence of inbreeding depression exists for cheetahs (Hedrick 1987; Caughley 1994; Wielebrowski 1996). Because the rate of mutation for quantitative traits per genome is thought to be of similar magnitude to the rates of mutation for minisatellites and microsatellites, variation in fitness traits is not unexpected even in the absence of variation in allozyme loci (see discussion in Hedrick 1996; Soulé & Zegers 1996).

Overall, the molecular genetic information on the cheetah may well provide insight into its population biology, but the problems related to its numbers in the wild are probably multifold and not entirely understood. As discussed by Caro and Laurenson (1994), the main source of mortality in wild cheetahs appears to be killing by lions (*Panthera leo*), but changes in the habitat by humans also appear to have had negative consequences. Furthermore, cheetahs in southern Africa, which appear to have somewhat lower genetic variation than those in eastern Africa, are much higher in density and are less endangered. Even in captivity, diet, husbandry, and understanding of mating behavior appear to be of greater significance than genetic considerations to successful breeding and maintenance. It is important to recognize, however, that it is often not possible or meaningful to attribute birth and deaths to purely genetic or nongenetic causes. For example, greater predation could be related to inbreeding depression.

What began as a possible case of genetic vulnerability has lately become a more complicated story involving issues of husbandry, predation, and habitat modification. The history of the cheetah in conservation biology may eventually be of use because it urges caution when few of the facts are known. Obviously, it behooves conservation biologists who wish to use genetics in endangered species studies to carefully qualify the implications of their findings and not to overemphasize their significance. If not, as in the cheetah story, genetic information may be discarded, rightly or wrongly, when it may be of real value.

Pacific Salmon

The current crisis in the conservation of Pacific salmon has been caused to some extent by the lack of application of small-population thinking to the management of wild salmon. Serious declines in salmon from the Columbia River, much of it caused by deterministic factors such as hydroelectric development, have been recognized for over 100 years (Allendorf & Waples 1995). One response was a large system of hatcheries and other programs specifically designed to offset losses from hydroelectric development. Beyond these programs, salmon management has responded to these declines largely through the regulation of fisheries based upon the principles of stock-recruitment and maximum sustained yield (Ricker 1954; Beverton & Holt 1957). Fishery managers have attempted to maximize surplus production (i.e., fish available for the catch) by maintaining the number of spawners at an abundance at which, according to stock-recruitment theory, they are likely to be most productive.

It has long been recognized that the fundamental unit of replacement of recruitment for anadromous (migratory) salmonids is the local population because of its homing behavior (Rich 1939; Ricker 1972). An adequate number of individuals in each of the small, local reproductive populations is needed to ensure persistence in the face of demographic, environmental, and genetic uncertainty. The homing of salmon to their natal streams produces a network of local reproductive populations that are distinct and adapted to specific environmental conditions. Groups of local salmon populations may function as metapopulations on a short time scale, and on an evolutionary time scale, most salmon populations are probably connected by migration, straying, or recolonization from other populations. Such connectedness may homogenize neutral genetic markers to some extent over local populations, but adaptive differences may remain in spite of gene flow.

The distinction between the fished stock and the local reproductive population is critical (Beverton et al. 1984). In practice, it has been extremely difficult to regulate losses on the basis of individual local populations. Thousands of local populations make up the West Coast salmon fishery, and many of these are likely to be intermingled in any particular catch. The result of regulating fishing on a stock basis and ignoring the reproductive units that together constitute a stock has been the disappearance or extirpation of many local populations (Clark 1984).

Caughley recommends that extirpated populations be replaced by restocking through translocation. This recommendation ignores the potential importance of genetically based local adaptations. Attempted translocation within the range of Pacific salmon have generally not been successful, in either North America (Withler 1982) or Asia (Altukhov & Salmenkova 1987). For example, efforts to reintroduce sockeye salmon (*Oncorhynchus nerka*) into appropriate habitat in the Fraser River system generally have failed. This has been particularly true of efforts to introduce lower-river stocks into upriver areas. Sockeye salmon from the lower Fraser River apparently lack the genetic (physiological) capacity to store energy reserves sufficient for the long migration into upriver areas that were depleted after a rock slide impeded upstream migration early in this century (Foerster 1968).

In addition, Riddell (1993) detailed an example from the Adams River, a tributary of the Fraser River. A logging dam built in 1908 blocked access of sockeye salmon to the upper Adams River from 1908 to 1921; these runs had been among the largest sockeye runs in the Fraser River system. This area has 1.2 million m^2 of spawning area, which should be sufficient to support 6 million adult sockeye per year based on productivity of other sockeye populations in the area. Sixteen attempts between 1949 and 1975 to reintroduce sockeye to these spawning areas were not successful in reestablishing the run. Today, only a few fish return to spawn in the upper Adams River.

Such observations provide strong evidence that many spawning populations of anadromous salmonids exhibit highly specific local adaptations for a number of different traits. These adaptations are likely to be the result of genetic differences between local populations at many loci. On this basis we expect it to be difficult to "replace" a local population with transplants from non-local populations. Only by understanding that the fundamental unit in salmon is the local population, and not the ocean stock, are these complexities apparent. Of course, one should not assume that other species besides salmon necessarily have specific adaptations unless they are demonstrated directly or suggested by genetic evidence, particularly when the per-generation migration is large. Even in salmon successful transplants of the nonanadromous kokonee are quite common.

Melding of the Paradigms

Caughley ends his essay on a positive point and suggests that "each paradigm has much to learn from the other and in combination they might enlarge our idea of what is possible." He gives several examples that illustrate situations in which both approaches contribute to preventing extinctions. The prime example is the Lord Howe Woodhen (*Tricholimnas Sylvestris* (Sclater)) for which introduced feral pigs (*Sus scrofa*) were identified through various experiments as the ultimate cause of the decline of the population. While this identification was taking place, the remaining birds were in a captive breeding program (this program was designed primarily to produce more woodhens before extinction [Miller & Mullette 1985] and did consider maintenance of genetic variation and avoidance of inbreeding). A second example is the interaction of metapopulation dynamics and habitat fragmentation as a cause of extinction. For example, the revision of timber-harvest practices to accommodate (partly) the Northern Spotted Owl was the result of PVAs that revealed that changes in the distribution of habitat across the landscape can, through local population processes, cause extinction (Lande 1988*b*). Contrary to Caughley's assertion that PVA ignores external influences on population's rate of increase, it is an excellent tool for integrating deterministic and stochastic factors. What PVA models bring to the analysis of wildlife populations is the consideration of stochastic processes, but they do not leave out the deterministic threats of habitat loss and alteration, over-harvest, and the impact of exotics.

The different approaches discussed by Caughley have much in common because they both focus on the fate of a given species. As suggested by Caughley and supported by us, a broader understanding of the factors influencing endangerment and extinction, based on an inclusive approach to PVA should be our goal.

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PAULAY 1994

Biodiversity on Oceanic Islands: Its Origin and Extinction[1]

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Abstract

SYNOPSIS. The isolation and small size of oceanic islands make them attractive models for studies of diversification; the sensitivity of their biota makes them important subjects for studies of extinction. I explore the origin of island biotas through dispersal and *in situ* diversification, and examine the fate of these biotas since human contact. Island biotas start out depauperate and disharmonic, facilitating the survival of relict taxa and stimulating adaptive radiations. The often highly restricted range and small population size of insular species, together with their limited diversity of defenses, make island biotas particularly vulnerable to extinction, largely through habitat loss or interactions with introduced species.

SPIELMAN ET AL
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Most species are not driven to extinction before genetic factors impact them

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There is controversy concerning the role of genetic factors in species extinctions. Many authors have asserted that species are usually driven to extinction before genetic factors have time to impact them, but few studies have seriously addressed this issue. If this assertion is true, there will be little difference in genetic diversity between threatened and taxonomically related nonthreatened species. We compared average heterozygosities in 170 threatened taxa with those in taxonomically related nonthreatened taxa in a comprehensive metaanalysis. Heterozygosity was lower in threatened taxa in 77% of comparisons, a highly significant departure from the predictions of the no genetic impact hypothesis. Heterozygosity was on average 35% lower (median 40%) in threatened taxa than in related nonthreatened ones. These differences in heterozygosity indicate lowered evolutionary potential, compromised reproductive fitness, and elevated extinction risk in the wild. Independent evidence from stochastic computer projections has demonstrated that inbreeding depression elevates extinction risk for threatened species in natural habitats when all other threatening processes are included in the models. Thus, most taxa are not driven to extinction before genetic factors affect them adversely.

There is controversy about the impact of genetic factors on extinction risk for threatened species and populations in nature (1). Species population sizes are reduced by habitat loss, overexploitation, impact of introduced species, and pollution until they reach a point where stochastic factors further elevate extinction risk (2). Stochastic factors encompass demographic, environmental, and genetic stochasticity and natural catastrophes. Threatened species typically have small and/or declining populations, such that inbreeding and loss of genetic diversity are unavoidable. In random mating populations, neutral genetic variation is lost and inbreeding accumulates, as follows:

$$H_g/H_0 = [1 - 1/(2N_e)]^g = 1 - F, \quad [1]$$

where H_g is the heterozygosity at generation g, H_0 the initial heterozygosity, N_e the long-term effective population size, and F the inbreeding coefficient (1). Inbreeding reduces reproduction and survival in essentially all well studied species (1, 3), reduced population heterozygosity is associated with reduced population reproductive fitness (4), and inbreeding depression increases extinction risk (5). Further, loss of genetic diversity reduces the ability of populations to evolve to cope with environmental change (1, 6). Thus, reduced heterozygosity is a marker of populations with reduced reproductive fitness and an elevated risk of future extinction caused by genetic factors, irrespective of the cause of the initial decline.

However, in an influential review, Lande (7) argued that "demography may usually be of more immediate importance than population genetics in determining the minimum viable size of wild populations." This argument has been widely interpreted to mean that ecological and demographic factors would typically drive threatened populations to extinction before genetic factors had time to impact them adversely (8–14). Although Lande (15) subsequently modified his views, it was not a retraction of the "no genetic impact" scenario, but a consequence of his later view that mutational accumulation contributes substantially to extinction risk.

Two studies have reported adverse genetic impacts on extinction risk in populations in the wild (16, 17), and the generality of the no genetic impact hypothesis (7–14) has been questioned (1). Inbreeding and reduced genetic diversity were associated with elevated extinction risk in wild butterfly populations (16), and extinction rates were markedly higher in populations of the plant *Clarkia pulchella* with higher versus lower inbreeding (17). Do these studies indicate that genetic factors usually contribute to extinctions, or are they special cases? It is critical to resolve this issue, so that threatened taxa can be managed appropriately.

Evaluating comprehensively the role of genetics in extinction for a diversity of taxa by experiments on wild populations would be an enormous task and quite impractical in the short term. Furthermore, conservation biology is a crisis discipline where it is not reasonable or practicable to wait for data collection before making decisions (18). However, a comparison of published data on genetic diversity in threatened and related nonthreatened taxa will provide an overall perspective, as threatened taxa are considered to be on the path to extinction. If the no genetic impact hypothesis (7–14) is correct there should be little difference in genetic diversity between threatened and taxonomically related nonthreatened taxa. Conversely, if most threatened taxa do indeed show less genetic diversity than related nonthreatened taxa, then this is strong evidence that genetic factors are adversely impacting these taxa.

Methods

We carried out a comprehensive metaanalysis to examine this hypothesis by using the internationally recognized IUCN-The World Conservation Union Red List threatened categorization system (19) that comprises critically endangered, endangered, and vulnerable taxa and applied it to identify threatened species and subspecies and taxonomically related nonthreatened taxa. Additional analyses were done on other IUCN-listed categories of extinct, extinct in the wild, lower risk, and data deficient. Generally, pairs of taxa were from the same genus or family, but some were at the class level. Analyses were done on percentage difference in heterozygosity between threatened and the nearest related nonthreatened species or group of species, based on data for allozymes, microsatellites, and minisatellites (paired comparisons only involved the same markers). Data from listed species were paired with data of the same type (either expected or observed heterozygosity, and either from allozymes or micro-

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Abbreviations: H_t, average heterozygosity in threatened taxa; H_{nt}, average heterozygosity in taxonomically related nonthreatened taxa.

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Table 1. Percentages of threatened taxa with lower heterozygosity than taxonomically related nonthreatened taxa ($H_t < H_{nt}$) in a range of major taxa and the magnitudes of those differences

Taxon	$H_t < H_{nt}$, %	Median difference, %	Mean difference, %	*n*	*P*
All	77	40	35	170	<0.0005
Animals	78	38	35	134	<0.0005
Vertebrates	78	35	35	129	<0.0005
Homeotherms	81	43	40	94	<0.0005
Mammals	84	46	42	63	<0.0005
Birds	74	40	35	31	0.001
Poikilotherms	69	26	20	35	0.001
Invertebrates	80	67	37	5	0.140
Plants	75	57	38	36	<0.0005
Angiosperms	81	58	40	21	0.005
Gymnosperms	67	51	35	15	0.012

n, Number of threatened taxa; *P*, probabilities based on Wilcoxon's signed rank tests.

satellites or minisatellites) from the most closely related nonlisted species or the weighted (according to sample size) average of the most closely related species. Generally, pairs were from the same genus or family, but some were at the class level. If expected Hardy–Weinberg heterozygosity and observed heterozygosity were both available, the expected was used as it is least affected by the size of the sample (20). If allozyme and microsatellite pairs were available for the same taxon, the combined weighted (measure × no. sampled × no. of loci tested) average was used. Table 2, which is published as supporting information on the PNAS web site, contains full details of the threatened taxa, the related nonthreatened taxa, and the sources of data.

Major Taxa. Major taxa were delineated according to the amount of data obtained. Thus, plants were subdivided into gymnosperms and angiosperms. As there were more data, animals were categorized as invertebrates (no further subdivision) and vertebrates, which were further subdivided into poikilotherms (fish, amphibia, and reptiles), homeotherms, birds, and mammals.

Data Analyses. The null hypothesis was that the genetic diversity of threatened taxa does not differ from that of nonthreatened taxa. The alternative hypothesis was that threatened taxa have less genetic diversity than comparable nonthreatened taxa. Thus, the statistical tests were one-tailed.

The common metric used was the percentage difference in heterozygosity. When a nonthreatened taxon had zero heterozygosity, this percentage was infinite. In simulations using the data set, we found that the use of only the nonthreatened taxon as the divisor gave biased estimates of the true differences, but the use of the larger of the threatened or nonthreatened heterozygosities as the divisor gave unbiased estimates of the true differences. Consequently, we used the larger measure of heterozygosity of each pair as the denominator [100 × (nonthreatened − threatened)/nonthreatened or 100 × (nonthreatened − threatened)/threatened]. The larger heterozygosity is more likely to represent the former heterozygosity for the taxon. Percentage difference in heterozygosity has a firm theoretical and conservation basis and is also interpretable as the effective inbreeding coefficient (1). The use of nonthreatened heterozygosities as the divisor throughout does not alter the conclusions.

Because the data are not normally distributed, nonparametric Wilcoxon's signed rank tests were performed on the difference in heterozygosity of each threatened taxon compared with the most closely related available taxon or taxa not included in the IUCN Red Lists. We tested for differences among the different Red List categories (critically endangered, endangered, vulnerable, lower risk, and data deficient) by using Kruskal–Wallis tests. For this test, data on extinct plus extinct in the wild (combined), lower-risk, and data-deficient taxa were added. The distribution of listed species with lower heterozygosity than closely related nonlisted species among major taxa and among IUCN Red List categories were investigated by using contingency χ^2 and Kruskal–Wallis tests.

As publication bias (file drawer effect) may affect the conclusions of metaanalyses (21), we tested for bias by regressing percentage difference between threatened and nonthreatened taxa on W (sample size × no. of loci) separately for allozymes and microsatellites, based on Palmer's recommendation (22).

Another test of the file drawer effect involved adding negative percentage differences to the data set until the results of the Wilcoxon's signed rank test became nonsignificant. This number indicates the minimum number of data points that must have remained unpublished for the results to be nonsignificant and can be compared with the number analyzed to indicate the existence or potential magnitude of this confounding problem.

All statistical analyses were carried out by using the MINITAB statistical package (release 13, Minitab, State College, PA).

Results

Overall, 77% of the 170 threatened taxa had lower heterozygosity than related nonthreatened taxa ($H_t < H_{nt}$), a highly significant deviation from equality as predicted by the no genetic impact hypothesis (7–14) (Table 1). Differences were significant for both allozyme and microsatellite data, and the two did not differ (see *Supporting Text*, which is published as supporting information on the PNAS web site). The distribution of percentage differences in heterozygosity is shown in Fig. 1, the median difference being 40% (mean, 35%).

The proportions of threatened taxa with $H_t < H_{nt}$ did not differ among major taxa ($\chi^2 = 5.4$, df = 5, $P = 0.366$). All major taxa with sufficient sample sizes showed a significant majority of threatened taxa with $H_t < H_{nt}$ (Table 1). The average magnitudes of the differences were also similar across taxa.

There were no indications of selective reporting bias in the data set. Regressions of percentage difference in heterozygosity between threatened and nonthreatened taxa on W (sample size × no. of loci) were nonsignificant for both allozymes ($b = 0.003$, $t = 1.60$, df = 122, $P = 0.11$, and $r^2 = 1.3\%$) and microsatellites ($b = -0.006$, $t = -1.40$, df = 49, $P = 0.17$, and $r^2 = 1.9\%$). Further details and additional analyses are given in *Supporting Text* and Table 3, which is published as supporting information on the PNAS web site.

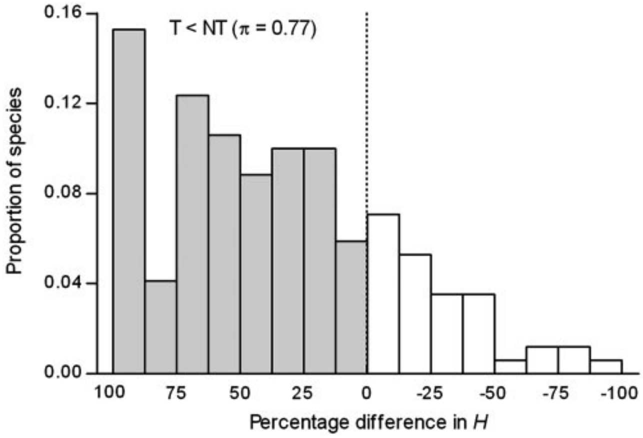

Fig. 1. Distribution of percentage differences in heterozygosity (H) between threatened (T) and taxonomically related nonthreatened taxa (NT). π is the proportion of taxa for which T $<$ NT, indicated by the shaded bars.

Discussion

A significant majority of threatened taxa in all major taxa with more than five data points showed lower genetic diversity than that in taxonomically related nonthreatened taxa. This finding is in conflict with the predictions of the no genetic impact hypothesis (7–14). Our results also refute the prediction that threatened mammals will show a difference in heterozygosity of <5% (23). The median and mean differences were 40% and 35%, respectively, vastly greater than the prediction. Prior studies in plants have noted lowered genetic diversity in rare versus common species and negative associations between genetic diversity and range size (24, 25), but did not connect these with endangerment and the no genetic impact hypothesis.

Taxa currently showing no adverse genetic impacts may still experience genetic impacts before extinction. For example, vulnerable taxa have approximately a 10% probability of extinction within 100 years (19), ample time for genetic impacts.

Are the reduced genetic diversities we found of sufficient magnitude to reflect adverse genetic impacts and elevated extinction risks? We were unable to determine whether genetic factors have contributed to the current threatened status of the taxa in our study. However, reduced genetic diversity is a marker indicating that their reproductive fitness is already compromised and that their subsequent extinction risk is elevated. Each of the essential links between reduced genetic diversity and subsequent extinction risk has been verified. First, reduced genetic diversity has been shown to reduce times to extinction under changing environments (1, 6). Second, from Eq. **1** the difference in heterozygosity is a measure of the inbreeding coefficient of a taxon. As loss of reproductive fitness is related to the inbreeding coefficient, a positive correlation between heterozygosity and population fitness is predicted and has been verified (4). Inbreeding depression has been shown to increase extinction risk in laboratory and wild populations (1, 16, 17, 26–28). The 40% median percentage reduction in genetic diversity between threatened and nonthreatened taxa corresponds to an inbreeding coefficient where deliberately inbred laboratory populations show elevated extinction risks (1, 29, 30), and inbreeding depression has greater impact in more stressful natural environments than in benign captive environments (3, 27, 28).

Third, computer projections demonstrate that inbreeding depression adversely affects the extinction risk of threatened species in the wild even when all other demographic, environmental, and catastrophic factors are operating (5). Computer projections using data for 20 threatened species showed 24–31% reductions in median times to extinction when inbreeding depression for juvenile survival was included in the models, compared to simulations where inbreeding depression was omitted. This result is conservative as inbreeding depression of only 3.14 diploid lethal equivalents for juvenile survival was applied, whereas actual levels in the wild are ≈12 lethal equivalents spread over the full life cycle (31). With the latter level of inbreeding depression, there is a 78% projected reduction in median time to extinction (unpublished data). In addition, small natural populations of a topminnow fish, a greater prairie chicken, and a Swedish adder all have declined in numbers, in part because of inbreeding, and recovered after outbreeding (32–34). Thus, our results refute the view that species are typically driven to extinction before genetic factors have time to impact them.

It is not possible given current knowledge to answer with precision the question of when the genetic effects of lowered diversity are of sufficient magnitude that they must be directly managed. The answer will depend on the inbreeding coefficient and thus on effective population size and number of generations, as indicated by Eq. **1**. Inbreeding levels where impacts will be important will be somewhat lower when the prior rate of inbreeding is lower and the potential for purging higher (1). It is also likely to vary among species, particularly in relation to their population growth rate (5). With rapid environmental change, the levels of inbreeding and loss of genetic diversity where adverse genetic impacts are expected will be lower than for stable environments (1, 27, 28). Estimated times to extinction for different-sized housefly populations in a benign captive environment approximated the effective sizes in generations (1).

Why does the no genetic impact hypothesis (7–14) not apply to most threatened taxa? There are four factors where subsequent information has changed perceptions since Lande's 1988 paper (7) in ways that would have led to underestimates of the impact of genetic factors. First, ratios of effective population size to census size have subsequently been found to average 0.11 (35), much lower than assumed in 1988. For example, in 1991 Mace and Lande (36) assumed that the ratio was 0.2–0.5. Thus, inbreeding and loss of genetic diversity occur at a substantially greater rate than Lande would have assumed. Second, impacts of interactions between genetic and other stochastic factors may have been underestimated. Fluctuations in population size caused by environmental stochasticity and catastrophes reduce the effective population size and increase the rates of inbreeding and loss of genetic diversity (37). Third, information on inbreeding depression for the full life cycle in natural environments was very limited in 1988, so its impacts are likely to have been underestimated, based on data from captive populations. The most prominent data at that time reported 3.14 lethal equivalents for juvenile mortality in captive mammals (38), whereas the full impact of inbreeding depression in the wild has more recently been reported as almost 4 times that (31). Fourth, Lande (7) considered that natural selection was highly effective in purging deleterious alleles under slow rates of inbreeding, but purging has subsequently been found to have relatively small effects (1, 30, 39).

In conclusion, most threatened taxa have lower genetic diversity than closely related nonthreatened taxa, indicating reduced reproductive fitness and elevated extinction risks. Consequently, our results are not compatible with the hypothesis that most species are driven to extinction before genetic factors impact them.

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GINGERICH USGS PLATE-1

INTRODUCTION

Tinian, which lies in the western Pacific Ocean at latitude 15°N and longitude 145°W (fig. 1), is the second largest island (39.2 mi²) in the Commonwealth of the Northern Mariana Islands (CNMI). Fresh ground water is obtained from shallow wells that tap the surface of a freshwater lens found in an aquifer composed mainly of coralline limestone. The main water-supply well withdraws water with a chloride concentration ranging from 160 to 220 mg/L. Current (1999) pumping rates adequately supply the island residents but future demands are expected to be higher. To better understand the ground-water resources of the island and to learn more about the hydrology of oceanic islands, the U.S. Geological Survey (USGS) entered into a cooperative study with the Municipality of Tinian. The objective of the study, conducted between 1990 and 1997, was to assess the ground-water resources of the island.

This report presents some of the results of the study including a description of the island's geology and geography, the current land use, the water-production system, the thickness and areal extent of the freshwater lens, the water-table configuration and directions of ground-water flow. The report also discusses the relation of the changes in water-table elevation to daily and seasonal changes in ocean level.

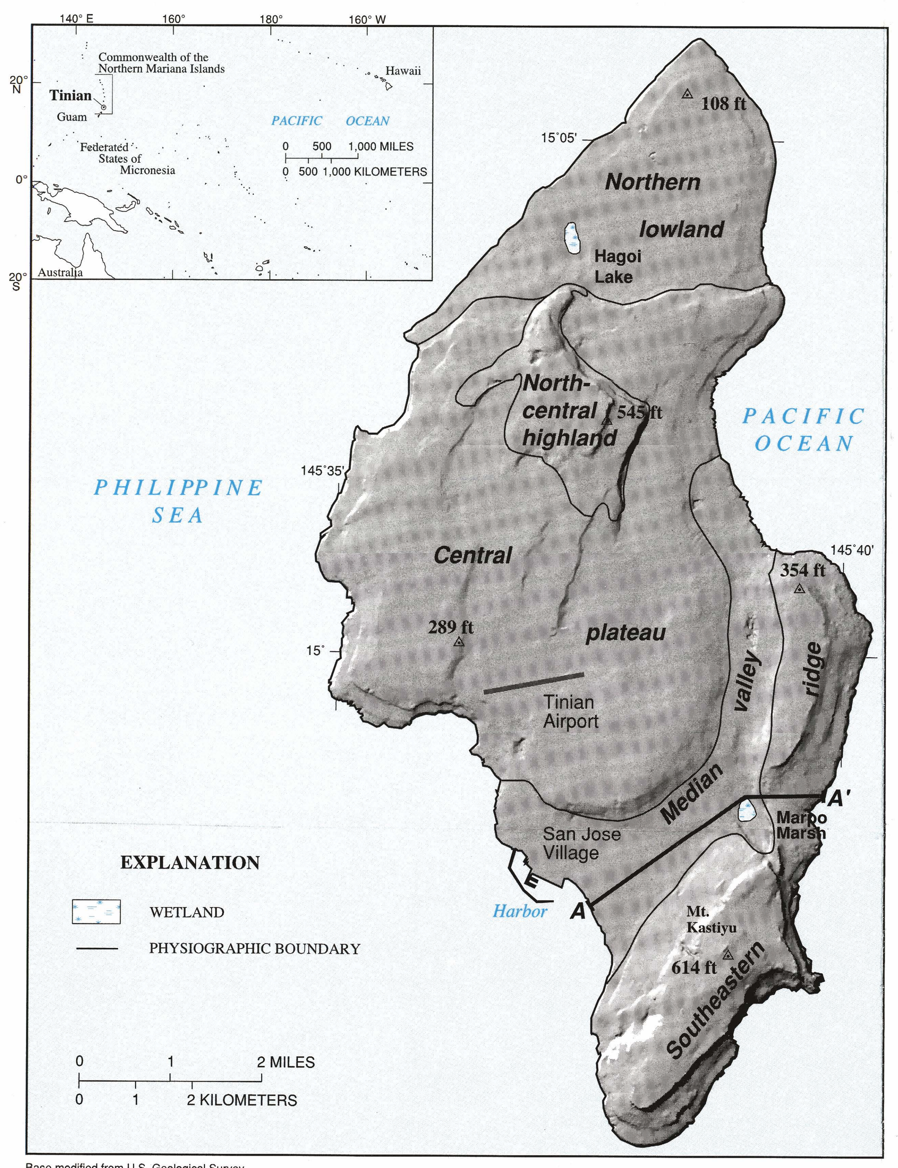

Figure 1. Location map and physiographic areas of Tinian (modified from Doan and others, 1960).

GROUND-WATER RESOURCE: THE FRESHWATER LENS

A portion of rainfall infiltrates and maintains a freshwater lens within the island. Some fraction of the infiltration can be withdrawn by wells, but high salinity can result from overpumping or dry weather.

A density difference between freshwater and saltwater creates a lens-shaped body of freshwater that floats on saltwater within the island (fig. 2), much the way an iceberg floats in the ocean. The primary aquifer on Tinian is composed mostly of well-indurated limestone consisting of coral, calcareous algae, and shells and skeletons of calcareous organisms (Doan and others, 1960). Water occupies small, intergranular pores and spaces between the accumulated material as well as larger voids, which originated as openings in the growth structure of the coral reef or developed later by dissolution of the calcium carbonate.

Theoretical freshwater lens and actual conditions on Tinian.--The Ghyben-Herzberg relation commonly is used to relate the thickness of a freshwater lens in an ocean-island aquifer to the density difference between freshwater and saltwater under hydrostatic conditions. Assuming a density difference of 0.025, a theoretical interface between freshwater and saltwater will be located at a depth below sea level that is 40 times the height of the water table above sea level (Todd, 1980). Instead of a sharp freshwater-saltwater interface, however, freshwater is separated from saltwater by a transition zone in which salinity grades from freshwater to saltwater (fig. 2A). In many field studies, the theoretical Ghyben-Herzberg interface depth has been found to correspond to the depth of about a 50-percent mix of freshwater and saltwater. Under equilibrium flow conditions in freshwater-lens aquifer systems, the Ghyben-Herzberg relation may provide a reasonable estimate of freshwater depth if the transition zone is comparatively thin.

Definition of potable freshwater.--Salinity in a freshwater lens is gradational, from an upper freshwater core through the underlying transition zone to saltwater. A chloride concentration of 250 mg/L is the maximum contaminant level (MCL) for drinking water recommended as a secondary standard by the USEPA (U.S. Environmental Protection Agency, 1989). Secondary standards are not mandatory requirements, but instead establish limits for constituents that may affect the aesthetic qualities of drinking water (taste and odor, for example). In this report, freshwater is defined as water having a chloride concentration less than or equal to 250 mg/L (fig. 2A). Seawater has a chloride concentration around 19,200 mg/L (Thurman, 1990).

Ground-water flow, recharge, and temporal variations in lens size.--Water flows continuously in a freshwater lens. Rainfall infiltrates and recharges the aquifer, where frictional resistance to flow within the aquifer matrix causes the water to accumulate and a lens to form. Freshwater flows by gravity to the shore, where it discharges as diffuse seepage and as springflow at shoreline and submarine springs. On small islands, mixing in the transition zone results mainly from tidal fluctuations superimposed on the gravity-driven flow of freshwater toward the shore. Under conditions of steady recharge and no pumping the lens would have a fixed size. In reality, rainfall is episodic and seasonal, and lens volume fluctuates naturally with time. The lens discharges continuously throughout the year, but shrinks during dry periods when recharge diminishes or ceases. The lens expands during high recharge episodes, which commonly are clustered within a definable wet season.

Ground-water withdrawal from wells, saltwater upconing, and regional lens depletion.--Some fraction of the recharge can be withdrawn continuously by wells, in effect capturing a fraction of the natural discharge. The most efficient means of developing a thin lens is to locate widely spaced shallow wells where the lens is thickest and to maintain low uniform pumping rates at each well. This spreads withdrawal over a wide area and skims freshwater from the lens. The more widespread the withdrawal, the greater the fraction of recharge that can be withdrawn with acceptable salinity for drinking. Saltwater upconing can contaminate wells if the lens is too thin, if wells are too deep, or if too much water is withdrawn from a small area. Even if wells are designed and placed to minimize local upconing, the lens will gradually shrink to a size that is in balance with the withdrawal. This regional shrinkage raises the transition zone closer to the wells, potentially close enough to raise the salinity of pumped water. Shrinkage of the freshwater lens due to dry weather can also contribute to high salinity in wells.

Small island freshwater lens at true scale.--Typically, sectional diagrams of a freshwater lens are drawn with the vertical scale greatly exaggerated (fig. 2A). If the section is drawn with no vertical exaggeration (fig. 2B), the extreme thinness of the freshwater lens on a small island is more evident, as is the difficulty of withdrawing freshwater without causing saltwater upconing.

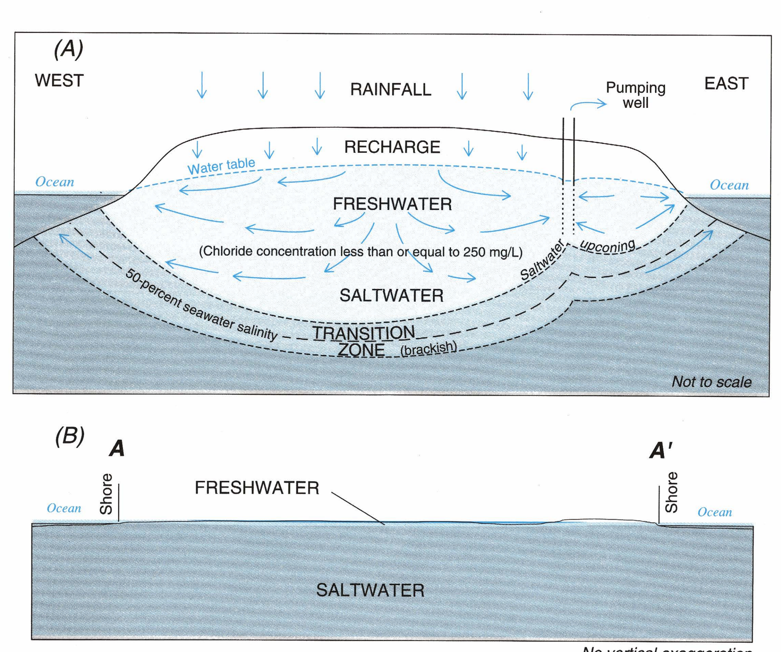

Figure 2. Diagrams of the Tinian freshwater lens. (*A*), Salinity structure and ground-water flow pattern, vertical dimension greatly exaggerated, (*B*), freshwater lens, no vertical exaggeration. Line of section shown in figure 1.

GEOGRAPHY

Flat terraces and plateaus dominate the surface terrain of Tinian and are separated by steep scarps. The greatest relief is formed by two relatively prominent blocks in the north-central and southeastern areas of the island. Land-surface elevation is near sea level at wetland depressions in southeastern and northwestern Tinian. The coast of the island largely consists of steep cliffs, most ranging from 20 to 100 ft high, separated by several small beaches and coves.

The island of Tinian is about 12 mi long and as much as 6 mi wide. The surface landforms can be divided into five major physiographic areas (fig. 1).

The southeastern ridge is the southernmost and highest part of the island and consists of a north and south ridge, separated by a gap near its midpoint. Steep slopes and cliffs that are as much as 500 ft high form the southeast boundary of the ridge. The highest point on Tinian is Mt. Kastiyu on the south ridge, at 614 ft altitude. To the northwest, the median or Marpo valley, a low, broad depression that separates the southeastern ridge from the central plateau, reaches an altitude of about 150 ft. The land surface intersects ground water at a depression in the valley, forming the Marpo marsh. The north and west flanks of the median valley steeply slope to the central plateau.

The central plateau extends northward and comprises all of central and some of the northern part of Tinian. The central plateau is broad and gently sloping with principal relief along its boundaries with the median valley and northern lowland. The north-central highland rises within the northern part of the central plateau, midway between the east and west coasts. The highest point of the north-central highland, 545 ft altitude, is exceeded in height only on the southeastern ridge. The northern lowland is generally flat and about 100 ft in altitude except at Hagoi Lake where the altitude is near sea level.

Two wetland areas near sea level are supplied perennially by ground water. Hagoi Lake in the northern lowland is a fresh to brackish water body surrounded by a marsh. The area of open water may extend to one-half mile in length during the wet season, and decrease to a marsh with little open water during the dry season. Marpo marsh in the median valley is a wetland with a small area of shallow open water.

LAND USE

The population of Tinian resides within and adjacent to the median valley. The rest of the island is unused grassland and secondary forest, except for areas of scattered grazing and occasional military training exercises. Land uses include one resort, small businesses, agriculture, and residential activities. Several quarries, a solid waste dump, and sewage-waste systems may affect the potential for ground-water contamination.

The population of Tinian, 2,631 people in 1995 (Bureau of Census, 1996), resides in a rural setting located in the median valley and parts of the adjacent central plateau and southeastern ridge, occupying about 25 percent of the island (Baldwin, 1995) (fig. 3). Most public and residential land-use activities take place in this area. Public land accounts for about 60 percent of the rural area and land use includes the airport, harbor, schools, cemetery, agricultural cooperatives, Marpo marsh, parks and beaches, and unused grassland and secondary forest. Residential and commercial land covers about 40 percent of the rural area and land use includes a casino resort, small businesses, farming, grazing, and housing. Ground-water contamination from these types of rural land use can be from many sources, including: nutrients from human and animal wastes emanating from septic systems and animal feedlots, fertilizers used on agricultural land, and detergents; pesticides and herbicides applied to homes and gardens; and petroleum compounds and solvents from spills, leaking underground storage tanks, and improper disposal.

About 75 percent of the island is grassland and secondary forest supporting minor land-use activities. About 40 percent of the grassland is reserved exclusively for military use in the northern part of the island, except for a U.S. Information Agency radio station operating in the southwestern part of this area. Military activities usually consist of occasional military exercises. About 60 percent of the remaining grassland and secondary forest, mostly on the central plateau and southeastern ridge, is used for scattered grazing of cattle and horses.

Other land uses that may affect the potential for ground-water contamination include several quarries used for extracting limestone building materials, and a solid-waste dump site near the west coast and south of the airport. All solid waste, including toxic materials and sewer waste from holding tanks, is dumped at the landfill. Tinian presently has no sewer facility and all residences and businesses use septic and seepage tanks, leaching fields, or holding tanks to dispose of sewage. The shallow depth to water and the abundance of pathways for infiltrating rainwater to travel in the limestone aquifer increase the potential for contaminants to reach and move through the aquifer rapidly.

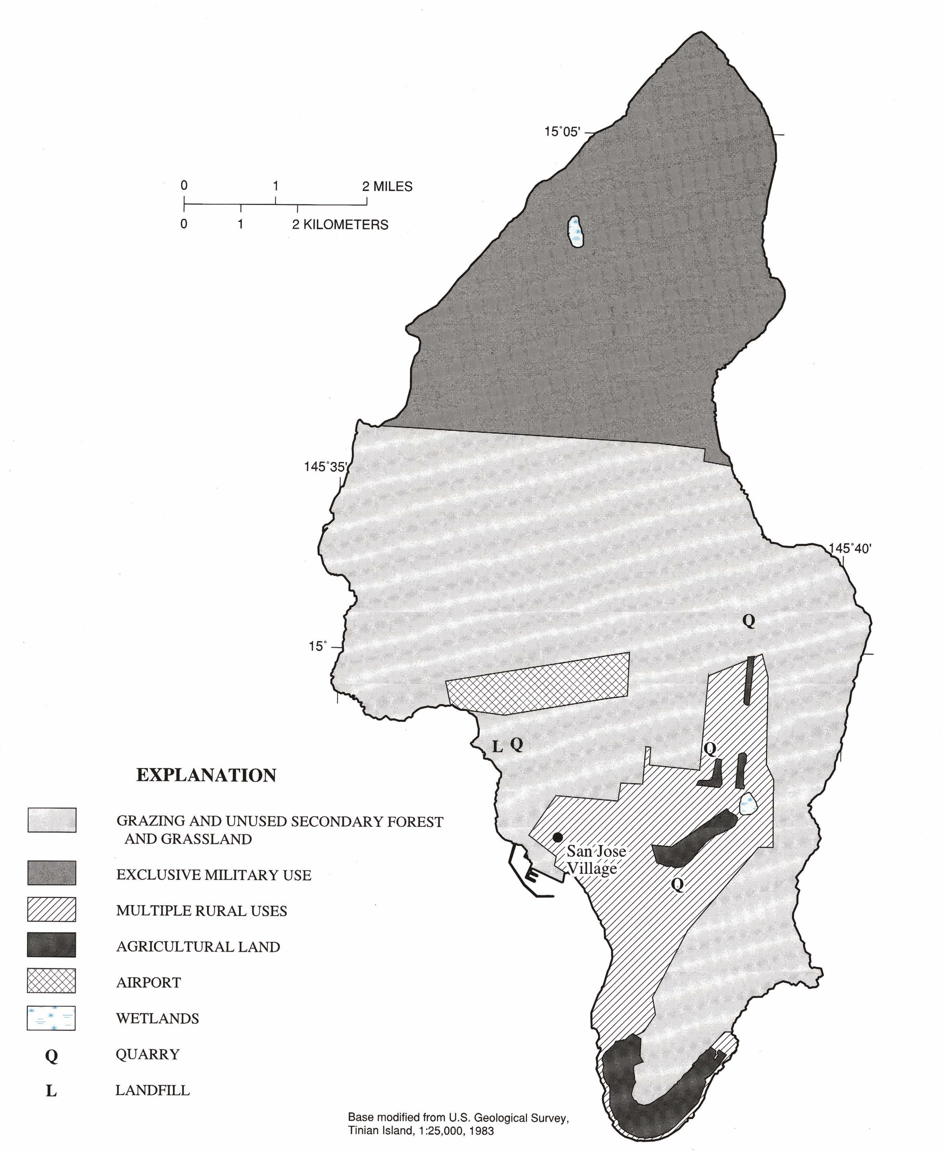

Figure 3. Generalized land use, Tinian (modified from U.S. Geological Survey, 1983; Young, 1989; and U.S. Department of Agriculture, 1994).

GEOLOGY

Volcanic rock forms the foundation of the island, predominantly below sea level, and coralline limestone dominates the lithology above sea level, comprising 98 percent of the surface exposures. The composition and natural porosity of coralline limestone usually cause high permeability, whereas the texture and poor sorting of the volcanic material usually cause low permeability. Faults transect the island throughout, complicating the structure and permeability of the rock units.

Four major geologic units make up the island (fig. 4). The Tinian Pyroclastic Rocks are the oldest exposed rocks, of late Eocene age, and underlie all other exposed rock units (Doan and others, 1960). This unit is exposed in the north-central highland and southeastern ridge and forms about 2 percent of the surface of the island. The thickness of the unit is unknown because the position of the base is undetermined. The Tinian Pyroclastic Rocks consist of fine to coarse-grained consolidated ash and angular fragments of volcanic origin. Outcrops usually are highly weathered and altered to clay.

The Tagpochau Limestone is of early Miocene age (Doan and others, 1960). It is exposed on about 15 percent of the surface on Tinian, principally in the north-central highland and the south part of the southeastern ridge. The unit thickens from zero to at least 600 ft in all directions away from the surface exposures of the Tinian Pyroclastic Rocks in the north-central highland and southeastern ridge. The Tagpochau Limestone is composed of fine to coarse-grained, partially recrystallized broken limestone fragments, and about 5 percent reworked volcanic fragments and clays. Surface exposures are highly weathered.

The Mariana Limestone is of Pliocene to Pleistocene age and is the most extensive unit areally and volumetrically above sea level. It comprises about 80 percent of the surface area, forming nearly all of the northern lowlands, the central plateau, and the median valley. The Mariana Limestone thickens from zero to at least 450 ft in all directions away from the surface exposures of the Tinian Pyroclastic Rocks and the Tagpochau Limestone. It is composed of fine to coarse-grained fragmented limestone, commonly coralliferous, with some fossil and algal remains, and lesser amounts of clay particles (Doan and others, 1960). Small voids and caverns are common in surface exposures. The Mariana Limestone differs from the Tagpochau Limestone in its higher coral content and lesser incidence of recrystallization.

The beach deposits, alluvium, and colluvium are of Pleistocene to Holocene age. These deposits cover less than 1 percent of the surface of Tinian, and may be as much as 15 ft thick. The deposits are composed of poorly consolidated sediments, mostly calcareous sand and gravel thrown onto beaches by waves, but also clays and silt deposited inland beside Hagoi Lake and Marpo marsh, and loose soil and rock material deposited at the base of slopes, especially in the north-central highlands.

The porous and well-washed character of coral reefs, and the high susceptibility of limestone to solution weathering favor high permeabilities in the limestone units. In contrast, permeabilities of the pyroclastic rocks tend to be low due to poor sorting and the high susceptibility of some volcanic minerals to chemical weathering and alteration to clays.

Normal faults transect the island throughout, displacing rock units relative to one another by generally less than 100 ft. The regional strike of the faults is north-south, approximately parallel to the trend axis of the Mariana Arc. Faults in limestone rock exposed at the surface commonly show weathered gaps along the fault, ranging from inches to feet in width; thus faults in limestone may represent narrow zones of relatively higher permeability than surrounding rock. The Tinian Pyroclastic Rocks and Tagpochau Limestone are dissected by faults concealed by the Mariana Limestone.

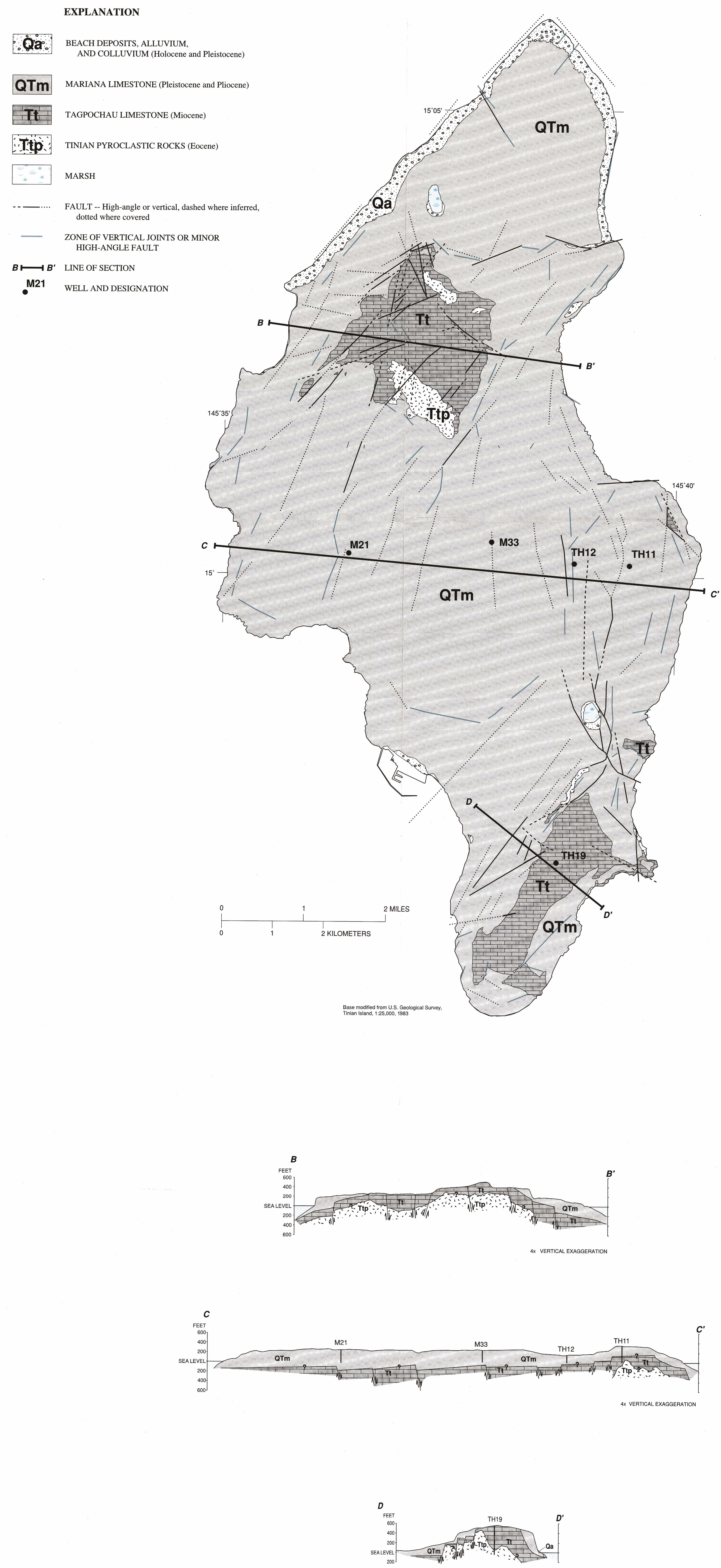

Figure 4. Generalized surficial geology and geologic sections, Tinian (modified from Doan and others, 1960).

GROUND-WATER RESOURCES OF TINIAN, COMMONWEALTH OF THE NORTHERN MARIANA ISLANDS

by
Stephen B. Gingerich and Daniel S. Yeatts

GINGERICH USGS PLATE-2

WATER-TABLE CONFIGURATION AND DIRECTIONS OF GROUND-WATER FLOW

The water table reaches its highest points in the volcanic rocks that are above sea level. Ground water flows from the north-central highlands and the southeastern ridge, where the water-table elevation is highest, towards the coast. A depression in the water table due to ground-water withdrawal may be causing ground-water flow patterns to change in the vicinity of the Municipal well.

The water table defines the top surface of the freshwater lens. Water-table contours for July 4, 1997 (fig. 5) show two mounds in areas where low-permeability pyroclastic rocks are above sea level and a localized zone of water-table depression in the vicinity of the Municipal well which was withdrawing water at the time of the measurements. Over most of the island, the water table is relatively flat and water levels are less than 2 ft above mean sea level. Water-level measurements made on other dates help determine where water-level contours are drawn. The highest measured water level in the limestone was 3.42 ft above mean sea level on December 7, 1997 in well M02 which is directly west of the north-central highland. The highest measured water level on the island was in the pyroclastic rocks on the southeastern ridge where water level was about 90 ft above mean sea level on May 29, 1997 in well TH19 (see table 1). The water table is expected to be similarly high in the pyroclastic rocks of the north-central highland but no wells are available there to provide water-level data.

On Tinian, the shape of the water table can be used to infer directions and rates of ground-water flow as well as the movement of contaminants dissolved in the flowing ground water. Fresh ground water will flow from areas of higher water level to areas of lower water level, in directions roughly perpendicular to the water-table contours (fig. 5). The water-table contours indicate that ground water moves radially from the north-central highland and the southeastern ridge and flows generally oceanward.

The water-table map reflects pumping conditions in the aquifer because withdrawal from the production well had been steady during the preceding months (fig. 8). Different water-table configurations would reflect different patterns of ground-water flow than that shown in figure 5. Drawdown from pumping diverts some of the oceanward ground-water flow to wells. To what degree the water-table configuration represents the long-term average configuration is not known. A longer-term average configuration could be determined by operating continuous water-level recorders at numerous wells and averaging the data over the desired time period, such as a year.

Preparation of the water-level map.--Measuring-point elevations at each well were surveyed by turning-point leveling to an accuracy of about 0.02 ft and referenced to the mean sea-level datum benchmark at the Tinian harbor. The average sea level, measured at the Tinian tide gage was 0.35 ft below mean sea level during the water-level survey. On July 4, 1997 between 7:00 a.m. and 11:00 a.m., the depth to water in each well was measured and subtracted from the measuring-point elevation at each well to obtain the height of water above mean sea level. At two wells, the Ushi well and the Municipal well, electronically recorded, 30-minute water-level data were available for the day of the survey. Because ocean tides caused water levels to fluctuate about 0.08 ft in the Ushi well and about 0.04 ft in the Municipal well during the 4 hours of the survey, the measurements from these wells were averaged over that time range. Other wells on Tinian are expected to have less daily variation from tidal fluctuations because they are much farther from the coast. Electronically recorded 30-minute water-level data from wells M02, M21, M29, and TH07 show less than 0.01 ft of daily tidal variation. Therefore, the shape of the water table shown in figure 5 probably is not significantly different than the shape of the water table with tidal fluctuations removed.

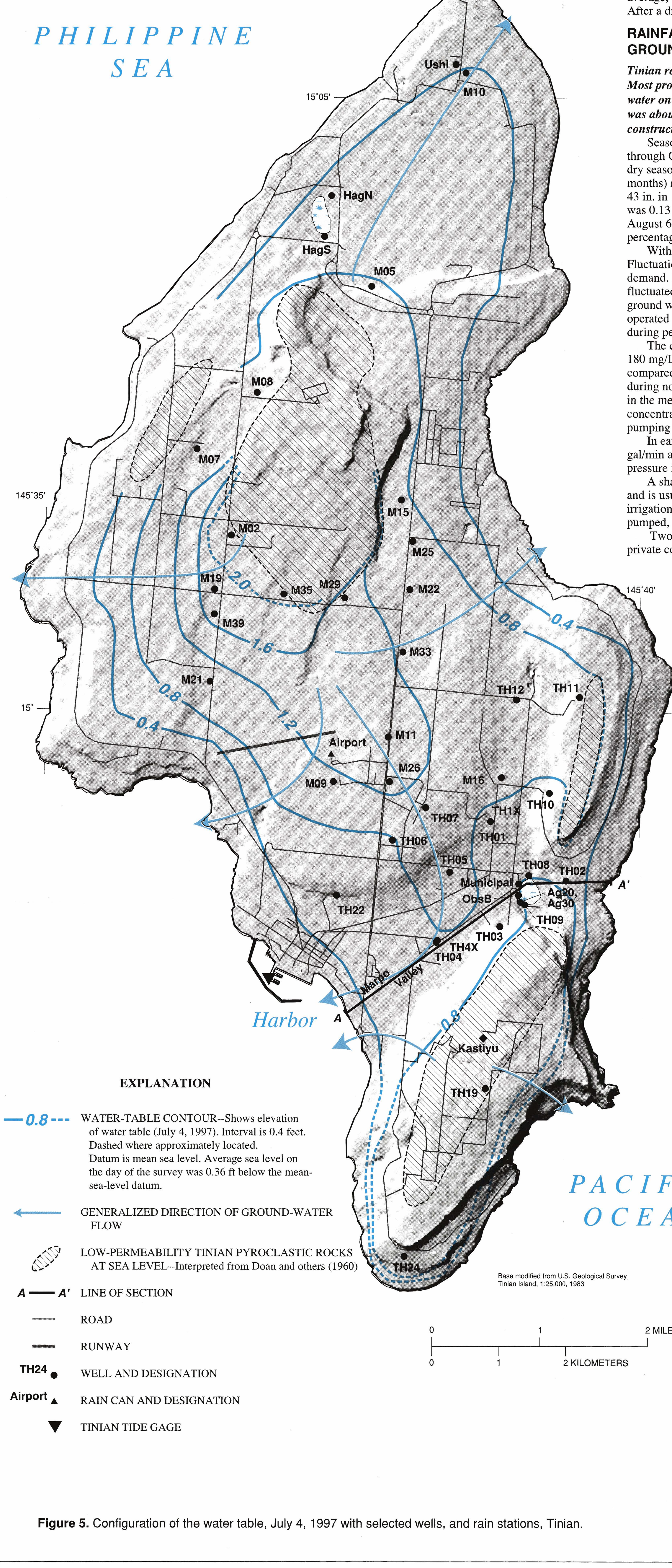

Figure 5. Configuration of the water table, July 4, 1997 with selected wells, and rain stations, Tinian.

THICKNESS OF THE FRESHWATER LENS

A vertical section through the median valley shows that the freshwater lens beneath the valley is thickest in the interior of the island and thins toward the coasts. The freshwater lens is about 40 ft thick in the middle of the island. The lens is slightly thinner near the Municipal well and the Marpo marsh possibly because of saltwater upconing due to ground-water withdrawal and evaporation.

Sectional view.--The thickness of the potable part (less than or equal to 250 mg/L) of the freshwater lens beneath the median valley (fig. 5, *A-A'*) is shown in a vertical section (fig. 6). The section shows that the freshwater lens is thickest in the center near well TH04 and thins toward the east and west coasts. The maximum thickness attained by the freshwater is about 40 ft. The freshwater lens is slightly thinner in the east than in the west, which indicates that saltwater may be upconing in the vicinity because of ground-water withdrawal at the Municipal well and evapotranspiration at the Marpo marsh.

Relation of transition zone to chloride concentrations at the Municipal well.--The chloride concentration of water pumped at the Municipal well depends on the position of the transition zone relative to the infiltration galleries in the well. The transition zone will rise when the wells are pumped (fig. 2). At the time of these measurements, the distance between the infiltration galleries and the transition zone was relatively large and the transition zone did not rise into the infiltration galleries at the maintained pumping rate. Chloride concentrations of pumped water remained relatively steady between 1990 and 1997 (fig. 8). Increased pumping rates may cause the transition zone to rise to the level of the infiltration galleries causing chloride concentrations in the pumped water to rise. Available data is insufficient for estimating the maximum withdrawal rate that will maintain acceptable chloride concentrations in the pumped water.

Preparation of the vertical sections.--Each well shown in the vertical section (fig. 6) was sampled at about 10-ft depth intervals starting at the water table using a 3-ft long bailer lowered to the desired depth in the open hole. Field measurements of the sampled water included temperature, specific conductance, and chloride-concentration. Where field measurements indicated that the salinity of the sample was higher than the sample from 10 ft above, the sample was submitted to the USGS Hawaii District laboratory in Honolulu for a more accurate chloride-concentration determination using titration. Therefore, several depth intervals having the same field chloride concentration as the next higher sample are not shown on the vertical section. The chloride concentration of a sample was considered to represent the chloride concentration in the aquifer at the elevation the sample was collected in the well. Water samples were collected from wells TH04X, TH08, and TH09 on March 5-6, 1997 and from well TH02 on May 23, 1997.

SEASONAL CHANGES IN THICKNESS OF THE FRESHWATER LENS

The thickness of the freshwater lens changed only slightly as a result of seasonal recharge and ground-water withdrawal. Freshwater thickness increased by about 3 to 5 ft during the wet season of 1993, a period of typical rainfall. Freshwater thickness decreased 1 to 2 ft during the dry season of 1994, when rainfall was higher than average.

Chloride concentrations deeper than 35 ft below sea level in monitor wells TH08 and TH09 (fig. 7) at the end of the 1993 wet season (July to October) were slightly lower than after the 1993 dry season (fig. 8), indicating that the freshwater lens had become slightly thicker. The number of sampling points in the wells is limited so the interpretation of the data is speculative. The thickening of the freshwater lens results from an increase in the amount of recharge to the aquifer relative to discharge during the wet season. In both wells, the base of potable water (250 mg/L chloride concentration) and the midpoint of the transition zone (9,500 mg/L chloride concentration) lowered only 3 to 5 ft between May and November 1993. Rainfall during this period was about 57 in. and the average rainfall for this same period during 1988-97 was also about 57 in. Therefore, the increase in thickness of the freshwater lens shown in figure 7 probably is typical of the average yearly change due to wet season recharge.

During the dry season (February to May), the thickness of the freshwater lens would be expected to decrease in response to a decrease in recharge. But the chloride-depth profiles (fig. 7) show only a slight thinning (1 to 2 ft) of the lens from November 1993 to May 1994. Rainfall during this period was about 28 in., 126 percent of the average rainfall during this same 6-month period for the years 1988-97. Because the 1994 dry season was wetter than average, the freshwater lens would not be expected to shrink to the same size as that measured the previous year. After a dry season of more typical rainfall, the lens would be expected to shrink slightly more.

RAINFALL, GROUND-WATER WITHDRAWAL, AND CHLORIDE CONCENTRATIONS IN GROUND WATER

Tinian receives about 79 in. of rainfall annually and has distinct wet and dry seasons. Six wells produce water. Most production comes from the Municipal well which pumps about 1 Mgal/d and was the sole source of potable water on Tinian for more than 50 years. The chloride concentration of pumped water from the Municipal well was about 180 mg/L during 1992-97, which is about 100 mg/L higher than initially measured after well construction in 1945.

Seasonal differences in rainfall define distinct wet and dry seasons on Tinian (fig. 8). The months of July through October (the wet season) receive about 61 percent (48 in.) of the annual rainfall; February through May (the dry season) receive 12 percent (10 in.) of the rainfall; and November, December, January, and June (transitional months) receive 27 percent (21 in.) of the rainfall. From 1988 to 1998, the total annual rainfall ranged from a low of 43 in. in 1998 to a high of 97 in. in 1994. The lowest amount of monthly rainfall recorded for the period of record was 0.13 in. in March 1995. The highest amount of daily rainfall recorded for the period of record was 12.9 in. on August 6, 1993 during tropical storm Steve. Rainfall from tropical storms and typhoons make up a significant percentage of the total annual rainfall and a lack of storms can significantly contribute to drought conditions.

Withdrawal and chloride-concentration data from the Municipal well for 1990-97 are shown in figure 8. Fluctuations in withdrawal correlate to changes in system condition or design, the pump efficiencies, and water demand. From 1990-97, ground-water withdrawal from this well has averaged about 1.2 Mgal/d and has typically fluctuated by about 10 percent over a year. Three 50-horsepower motors have been used since 1990 to extract ground water from this well. In March, 1996, one motor was upgraded to 75 horsepower. Pumps are typically operated at maximum capacity 24 hours per day, except when one or more pumps are turned off for maintenance or during periods of lower demand in the wet season.

The chloride concentration at the Municipal well did not change significantly during 1992-97, averaging about 180 mg/L, and ranging from 160 to 220 mg/L. Chloride concentration was usually slightly lower in the wet season as compared to the dry season. The average chloride concentration is about 100 mg/L higher than initially measured during non-pumping conditions after construction in 1945 (Lawlor, 1946), and 100 mg/L higher than at other wells in the median valley. Monitor wells TH08, TH09, and TH03 are near the Municipal well and show similar chloride concentrations, near 180 mg/L, indicating that the chloride concentration at these wells may be elevated from pumping at the Municipal well.

In early 1999, wells TH04 and TH06 were put into operation. Well TH06 is capable of producing about 60 gal/min and well TH04 can produce about 50 gal/min. These wells are used during peak demand hours to maintain pressure in the distribution system (Greg Castro, CUC Deputy Director, oral commun., 1999).

A shallow, 30-ft diameter well (well Ag30) is used seasonally to supply irrigation water to cooperative farms, and is usually operated for about 10 hours on alternate days of the dry season. When operated, withdrawal from the irrigation well is estimated to be about 500 gal/min. Chloride concentrations increase significantly when the well is pumped, from pre-pumping values of 180 mg/L to post-pumping values more than 500 mg/L.

Two other wells that are currently in use are wells M25 and M26. These wells were rehabilitated in 1987 by a private corporation and are each pumped at about 25 gal/min for ranch uses.

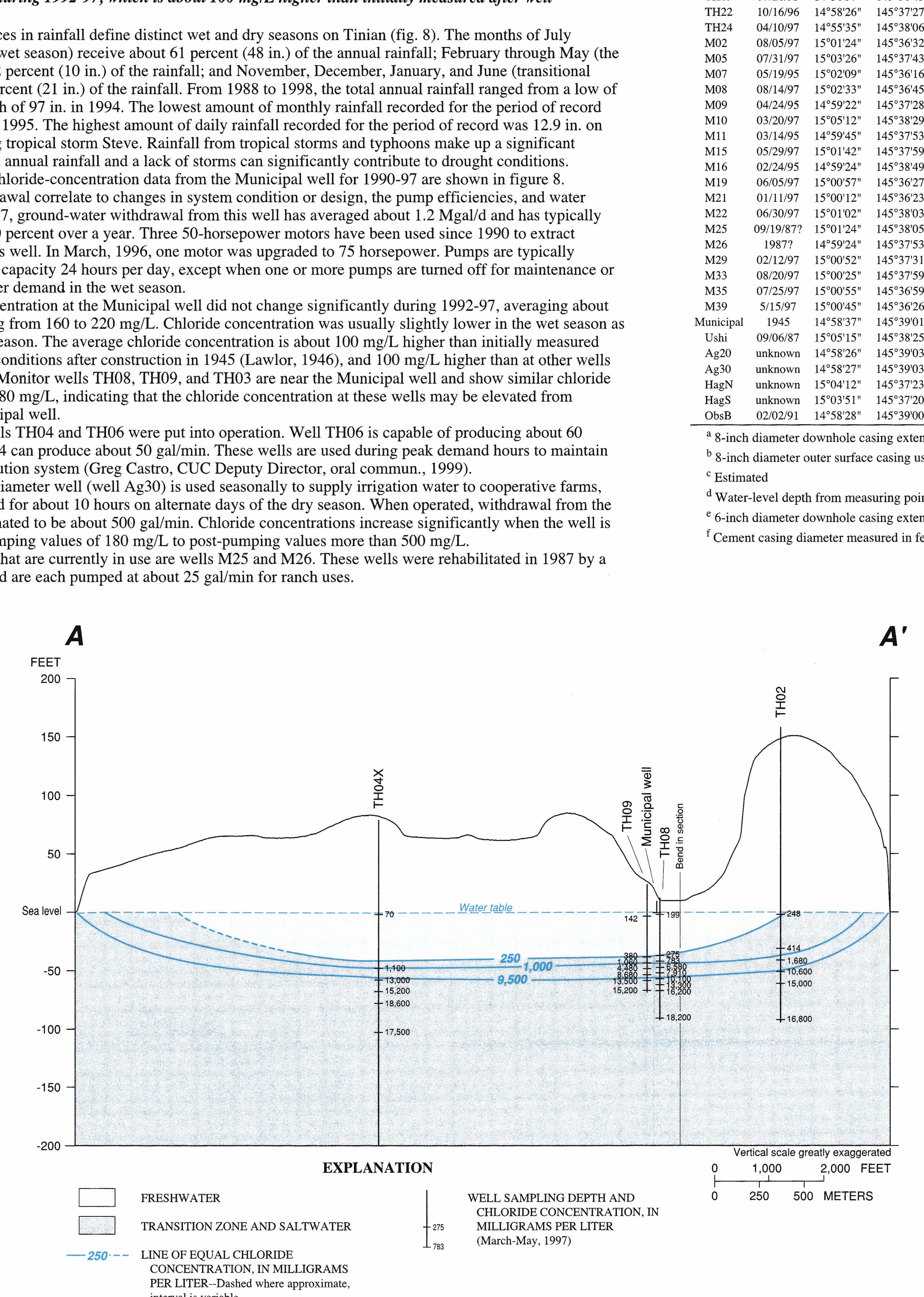

Figure 6. Thickness of freshwater lens (to a depth of 250 mg/L chloride concentration) and upper transition zone, Tinian, March 5-6 and May 23, 1997. Line of section is shown in figure 5.

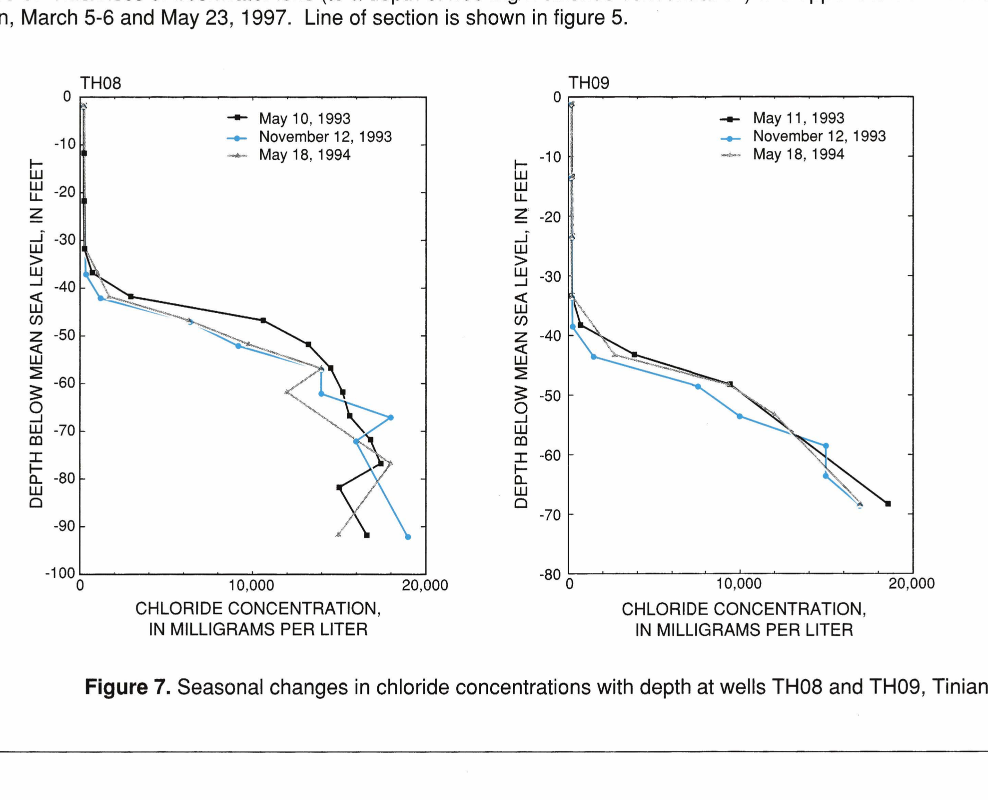

Figure 7. Seasonal changes in chloride concentrations with depth at wells TH08 and TH09, Tinian.

LOCATION AND WELL CONSTRUCTION OF SELECTED WELLS

Well-construction details of 40 wells that were drilled, rehabilitated, or monitored during the USGS ground-water study, 1990-97, are shown in table 1. The wells can be divided into three groups, defined by the periods of construction: USGS-drilled wells, 1993-97; U.S. military-drilled wells, 1944-45; and dug wells, 1930's. The Ushi well is an exception, drilled by the U.S. military in 1987.

The USGS drilled 17 monitoring wells (TH-designated well numbers, fig. 5 and table 1) during 1993-97 in the median valley and adjacent southeastern ridge and central plateau. Of the 17 wells, 12 are open holes and 5 are cased with PVC pipe and screened below the water table. All wells were drilled into the top of the freshwater lens except wells TH02, TH04X, TH08, and TH09 (fig. 5) which were drilled into the transition zone. These transition zone wells are important because they provide information about the temporal changes in thickness of the freshwater lens and underlying transition zone due to seasonal rainfall and ground-water withdrawal.

The U.S. military drilled 40 wells, mostly on the central plateau and north-central highland, and constructed one Maui-type horizontal well (presently known as the Municipal or Marpo well) on the northern edge of the Marpo marsh during 1944-45. All drilled wells were abandoned shortly after World War II. The USGS rehabilitated 16 of the 40 wells (M-designated well numbers, fig. 5) during 1995-97. The rehabilitated wells originally extended into the freshwater lens and were cased from land surface to well bottom with solid steel casing, perforated throughout the bottom 10 to 20 ft. Rehabilitation involved retrieving the old pump and pipe, re-drilling if necessary, and cleaning the hole to near the original depth. The well casing remains intact although some parts are heavily corroded. Well M29 was deepened into the transition zone. Two other military wells (M25, M26) were rehabilitated by a private corporation about 1987.

The Municipal well is a Maui-type infiltration gallery constructed by the U.S. military in 1945 (fig. 9). This well is the only well that was not abandoned after World War II, and supplied all of the potable water for Tinian until 1999 when two additional vertical wells were added to the system. The well withdraws about 1 Mgal/d from the limestone aquifer in a depression of the median valley. The well withdraws water from the upper part of the aquifer over a large area, which tends to maximize the amount of freshwater that can be withdrawn from an area while minimizing upconing of the transition zone. The infiltration gallery lies in a trench and consists of dual drainage tunnels 300 ft in length, covered with 1-1/2-in. graded coral gravel (Lawlor, 1946). The tunnels were made of 240 steel cylindrical bomb crates, connected end to end with hinged couplings and perforated. A sump at the midpoint of the tunnels constructed of two steel pontoons collects water from the tunnels and houses the pumps used to extract the water.

The Japanese administration dug more than 100 wells during the occupation of Tinian in the 1930's. All but a few were abandoned and filled. Four shallow wells ranging in diameter from 10 to 30 ft that penetrate the freshwater lens are included in table 1: Ag20, Ag30, HagN, and HagS (fig. 5). Wells Ag20 and Ag30 are both located on the southern edge of the Marpo marsh. The Ag30 well continues to be used seasonally as a source of irrigation water. Wells HagN and HagS are located on the north and south edge, respectively, of Hagoi Lake.

Table 1. Location and construction of selected wells, Tinian

[TH, USGS test hole; M, U.S. military well; Ushi, Ushi Point well; Ag20, Ag30, agricultural dug wells; HagN, HagS, Hagoi Lake, north and south dug wells; date well drilled is last day of rehabilitation for military wells (M) and last day of drilling for all other wells; measuring point is top of well casing except TH06, M25, M26 is top of PVC sounding tube, and Ag20, Ag30, HagN, HagS is top of cement wall; N/S, not surveyed. For military wells: hole bottom elevation is bottom of rehabilitated hole; casing bottom may extend below hole bottom elevation; top of open interval not known; casing bottom elevation and open interval elevation interpreted from Doan and others, 1960; open, open hole; perf, perforated casing; screen, screened casing]

Well number	Date well drilled	Latitude	Longitude	Measuring point altitude (feet)	Hole bottom altitude (feet)	Casing bottom altitude (feet)	Casing inside diameter (inches)	Type of open interval	Open interval altitude (feet)	Water-level altitude (feet)	Water-level date	Water-level time
TH01	09/17/96	14°59'03"	145°38'47"	117.46	-13	107	12	open	107 to -11	1.00	12/28/97	1200
TH1X	10/01/96	14°59'04"	145°38'47"	116.99	-15	107	6	open	107 to -15	0.78	07/04/97	0825
TH02	04/28/97	14°58'40"	145°39'25"	158.86	-94	149	8	open	149 to -94	0.52	07/04/97	0755
TH03	10/24/96	14°58'12"	145°38'48"	109.05	-22	99	8	open	992 to -22	0.71	07/04/97	0725
TH04	12/13/93	14°58'05"	145°38'18"	72.18	-18	51	8[a]	open	51 to -18	0.79	07/04/97	0720
TH4X	05/05/94	14°58'06"	145°38'18"	71.89	-268	52	8	open	52 to -268	1.26	03/06/97	1600
TH05	06/21/95	14°58'42"	145°38'24"	120.85	-18	111	8	open	11 to -18	0.94	07/04/97	0830
TH06	03/02/95	14°58'53"	145°37'55"	309.07	-13	-12	6	screen	8 to -12	0.79	07/04/97	0835
TH07	01/20/95	14°59'12"	145°38'11"	343.84	-20	-20	6[b]	screen	0 to -20	0.84	07/04/97	0840
TH08	01/29/93	14°58'39"	145°39'04"	8.24	-92	-92	4	screen	8 to -92	0.83	07/04/97	0745
TH09	02/03/93	14°58'25"	145°39'03"	6.70	-92	-68	4	screen	2 to -68	0.80	07/04/97	0730
TH10	10/09/96	14°59'20"	145°39'12"	163.74	-16	154	8	open	154 to -16	0.78	07/04/97	0750
TH11	02/25/97	15°00'03"	145°39'30"	339.66	-19	-17	6[b]	screen	3 to -17	0.85	07/04/97	0810
TH12	01/08/97	15°00'06"	145°38'53"	146.41	-13	136	8	open	136 to -13	0.90	07/04/97	0800
TH19	07/26/95	14°56'57"	145°38'45"	550[c]	-29[c]	543[c]	8	open	543[c] to -29[c]	90[c]	05/29/97	1025
TH22	10/16/96	14°58'26"	145°37'27"	96.61	-16	87	8	open	87 to -16	0.69	07/04/97	0715
TH24	04/10/97	14°55'35"	145°38'06"	N/S	-9[c]	302[c]	8	open	302[c] to -9[c]	311.39[d]	07/04/97	0700
M02	08/05/97	15°01'24"	145°36'32"	264.56	-12	-12	6	perf	? to -12	2.76	08/22/97	1040
M05	07/31/97	15°03'26"	145°37'43"	108.80	-13	-14	6[e]	perf	? to -13	0.88	07/31/97	1820
M07	05/19/95	15°02'09"	145°36'16"	241.35	-19	-17	6	perf/open	? to -19	0.98	07/04/97	1000
M08	08/14/97	15°02'33"	145°36'45"	266.07	-16	-16	6	perf	? to -16	1.09	08/22/97	0925
M09	04/24/95	14°59'22"	145°37'28"	265.08	-15	-13	6	perf/open	? to -15	0.94	07/04/97	0850
M10	03/20/97	15°05'12"	145°38'29"	95.00	-16	-14	6	perf/open	? to -16	0.42	07/04/97	1015
M11	03/14/95	14°59'45"	145°37'53"	292.03	-14	-14	6	perf	? to -14	1.25	07/04/97	0900
M15	05/29/97	15°01'42"	145°37'59"	193.84	-9	-7	6	perf/open	? to -9	0.81	07/04/97	0925
M16	02/24/95	14°59'24"	145°38'49"	153.39	-17	-15	8	perf/open	? to -17	0.82	07/04/97	0820
M19	06/05/97	15°00'57"	145°36'27"	247.92	-14	-16	6	perf	? to -14	1.76	07/04/97	0950
M21	01/11/97	15°00'12"	145°36'23"	243.29	-17	-14	6	perf/open	? to -17	1.07	07/04/97	0940
M22	06/30/97	15°01'02"	145°38'03"	222.73	-8	-15	6	perf	? to -8	0.98	07/04/97	0905
M25	09/19/87?	15°01'24"	145°38'05"	211.94	-88	-10	6	perf/open	? to -88	0.88	07/04/97	0915
M26	1987?	14°59'24"	145°37'53"	340.83	-30	330	6	open	330 to -30	1.32	07/04/97	0855
M29	02/12/97	15°00'52"	145°37'31"	247.04	-168	-17	6	perf/open	? to -168	1.26	07/04/97	0930
M33	08/20/97	15°00'25"	145°37'59"	235.63	-10	-12	6[e]	perf	? to -10	1.41	08/22/97	1055
M35	07/25/97	15°00'55"	145°36'59"	257.23	-13	-14	6	perf	? to -13	2.26	07/31/97	1725
M39	5/15/97	15°00'45"	145°36'26"	238.93	-11	-13	6	perf	? to -11	1.62	07/04/97	0945
Municipal	1945	14°58'37"	145°39'01"	9.76	-1	-1	20	perf	1 to -1	0.58	07/04/97	1000
Ushi	09/06/87	15°05'15"	145°38'25"	98.47	-19	-19	6	screen	-7 to -17	-0.09	07/01/97	1537
Ag20	unknown	14°58'26"	145°39'03"	7.10	-1	-1	20[f]	open	-1	1.57	07/02/97	1110
Ag30	unknown	14°58'27"	145°39'03"	5.08	-5	-5	30[f]	open	-5	0.80	07/04/97	0735
HagN	unknown	15°04'12"	145°37'23"	4.40	-2	-2	20[f]	open	-2	0.61	07/04/97	1030
HagS	unknown	15°03'51"	145°37'20"	7.54	-1	-1	10[f]	open	-1	0.67	07/04/97	1100
ObsB	02/02/91	14°58'28"	145°39'00"	7.45	-0.5	?	4	?	?	0.78	07/04/97	0740

[a] 8-inch diameter downhole casing extended above ground with 6-inch casing
[b] 8-inch diameter outer surface casing used as measuring point
[c] Estimated
[d] Water-level depth from measuring point
[e] 6-inch diameter downhole casing extended above ground with 8-inch casing
[f] Cement casing diameter measured in feet

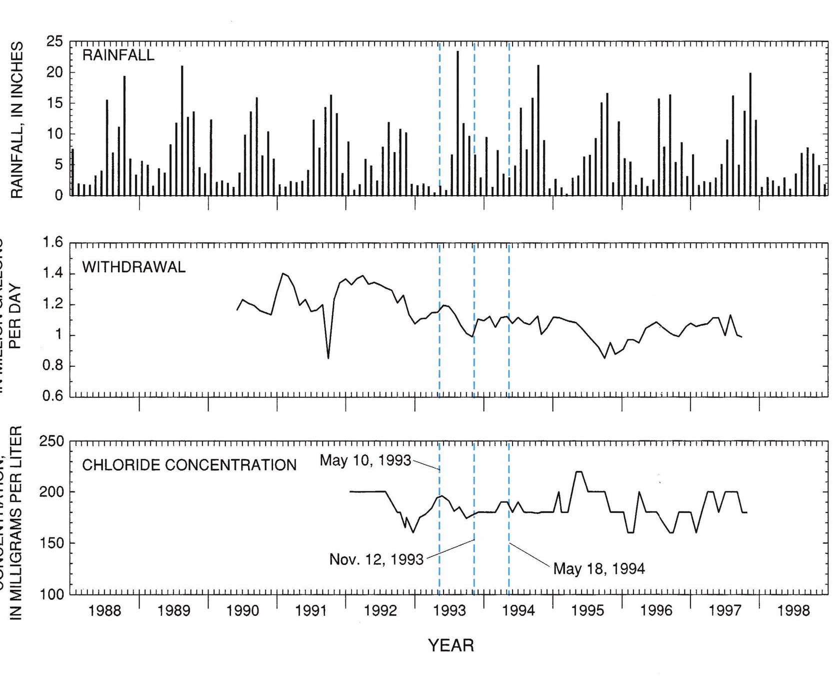

Figure 8. Rainfall, ground-water withdrawal, and chloride concentration at Municipal well, Tinian.

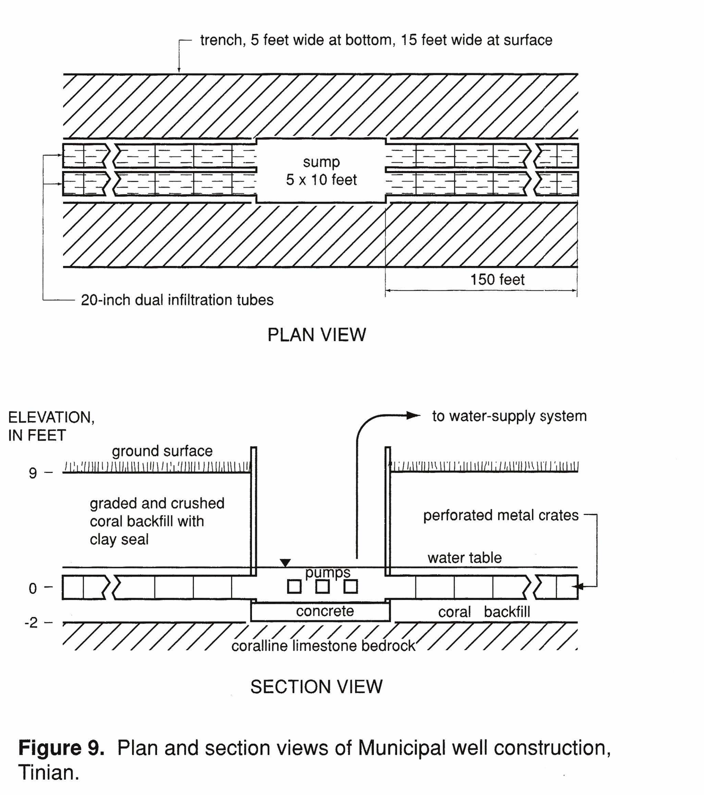

Figure 9. Plan and section views of Municipal well construction, Tinian.

WATER-LEVEL RECORDS

Water levels fluctuate daily as much as 0.5 ft in wells closest to the coast in response to ocean tides. Wells in the interior of the island typically do not show daily water-level fluctuations from ocean tides. Water levels in all wells rise and fall in response to non-tidal short- and long-term changes in ocean level and to changes in recharge. Water-table fluctuations caused by changes in recharge are difficult to evaluate because of the dominance of water-level changes caused by ocean-level variations.

The record of the water level in three wells between December 1 and December 15, 1992 shows how the water-table fluctuates in response to the ocean tide (fig. 10). The daily tidal signal from the ocean is attenuated as it travels through the aquifer and the daily fluctuation of the water table decreases with increasing distance from the ocean. The daily water-level changes in the Ushi well, 2,790 ft from the coast, averaged about 0.5 ft and the Municipal well, 4,080 ft from the coast, had daily water-level changes that averaged about 0.15 ft. Well M21, at 4,690 ft from the coast, had daily fluctuations that averaged about 0.01 ft. Three other wells (M02, M29, and TH07) that were monitored electronically by the USGS showed no daily tidal fluctuations; these wells are 7,660 ft, 9,630 ft, and 9,430 ft from the coast, respectively.

In addition to the daily fluctuation in water level caused by the ocean tides, water levels in wells also vary over longer time periods in response to non-periodic changes in ocean level and to rainfall (fig. 11). After removing tidal fluctuations, the ocean level at the Tinian harbor ranged from -0.4 ft to 0.5 ft altitude from January 1, 1997 to September 5, 1997, when the station was discontinued. During the entire period that the tide gage was operating (1990-97), the ocean-level record with the tidal fluctuations removed ranged from -0.7 ft to 1.2 ft altitude. The water-level records with the tidal fluctuations removed from the Ushi and Municipal wells show variations that correspond closely to the ocean-level record. Although the tide gage was discontinued in 1997, it is apparent that wells M29, M02, and TH07 also respond to the ocean level because the water-level records from these wells are similar to the Municipal well water-level record. The record from well M21 also corresponded to the ocean-level record but monitoring at this well was discontinued before the period shown on the plot, and therefore, is not shown.

The difficulty in determining the effects of recharge and withdrawal on the water table is illustrated in figure 11. For example, the decline in water level of nearly 0.7 ft in the Ushi well from January to March 1997 is due mainly to the decline in ocean level and cannot be reliably attributed to a decline in recharge during the annual dry season. With the exception of the water-level record from well M02, all of the variations in water level in the monitored wells appear to be directly in response to variations in ocean level with a little additional variation because of extreme rainfall. However, the effects of changes in recharge or withdrawal cannot be readily evaluated using these water-level records. The water-level rise of nearly 1 ft in well M02 during the end of December 1997 does not correlate with any of the other concurrent water-level records. The cause of this increase is unknown but is probably from recharge after an episode of extreme rainfall interacting with the nearby low-permeability volcanic rocks.

SUMMARY AND CONCLUSIONS

This report presents findings of a study of ground-water resources on Tinian, Commonwealth of the Northern Mariana Islands conducted from October 1990 through September 1997. The current water-supply system is expected to be insufficient for future population growth and development. The study was done to better understand and delineate the potable part of the fresh ground-water lens.

Ground-water resource.--The primary aquifer is coralliferous limestone and contains a freshwater lens that floats on saltwater near sea level. The freshwater lens is recharged by rain water, and the lens shrinks and expands in response to variations in recharge and ground-water withdrawal at wells. The salinity of water withdrawn from wells will rise if the withdrawal rate is too high or if rainfall is low for prolonged periods.

Geology, geography, and land use.--Limestone comprises about 98 percent of the surface exposures of the island, and dominates lithology above sea level, while volcanic rocks predominate below sea level and form the foundation of the island. The limestone rock commonly is coralliferous and highly porous, while the volcanic rock is composed of poorly sorted pyroclastic materials that have a lower porosity. The surface terrain is dominated by flat terraces and plateaus, separated by steep scarps. Five major land forms delineate the physiography: southeastern ridge, median valley, central plateau, north-central highland, and northern lowland. Most land-use activities are concentrated in 25 percent of the island within and adjacent to the median valley. Land use that may potentially contribute to ground-water contamination includes agricultural lots, septic fields, solid-waste dumps, and quarries.

Water-table configuration and ground-water flow.--The highest water levels occur in the vicinity of pyroclastic rocks that are above sea level. Water-table contours roughly parallel the perimeter of the north-central highlands and southeastern ridge. Water-table elevations are lowest at a depression in the median valley, and along the coast. Fresh ground water generally flows radially away from the north-central highlands and southeastern ridge, and flows toward the median valley and the coast, ultimately reaching the ocean.

Thickness of the freshwater lens.--The thickness of the freshwater lens is about 40 feet at the most inland well in a section through the median valley and near zero at the well closest to the coast. Withdrawal at the Municipal well and evaporation from the Marpo marsh may cause the potable part of the freshwater lens to be thinner and the transition zone to rise higher than would be expected under natural conditions in the vicinity of the well. The thickness of the freshwater lens at TH08 and TH09 increased about 3 to 5 feet after the wet season from May to November 1993 and the thickness decreased about 1 to 2 feet after the dry season from November 1993 to May 1994.

Rainfall, ground-water withdrawal, and chloride concentration.--The annual rainfall on Tinian averaged 79 inches from 1988 to 1998 and fell in distinct wet and dry seasons. The Municipal well, consisting of two parallel horizontal tunnels 300 feet in length, withdraws about 1 million gallons per day from a limestone aquifer in a depression of the median valley. Withdrawal rates generally decrease during the wet season in response to lower demand. The chloride concentration of the pumped water averaged about 180 milligrams per liter and ranged from 160 to 220 milligrams per liter during 1992-97. Periods of lower chloride concentrations roughly correlate to wet season months, and periods of higher concentrations correlate to dry season months.

Water-level records.--Ground-water level fluctuations closely correlate to ocean-level fluctuations. Daily tidal fluctuations strongly affect ground-water levels near the coast, but are attenuated and diminish with increasing distance from shore. Ground-water levels toward the interior of the island are more strongly influenced by seasonal, and other non-tidal ocean-level disturbances. Recharge is difficult to ascertain from changes in the water-table elevation measured in wells because the effect of ocean-level variations is so great.

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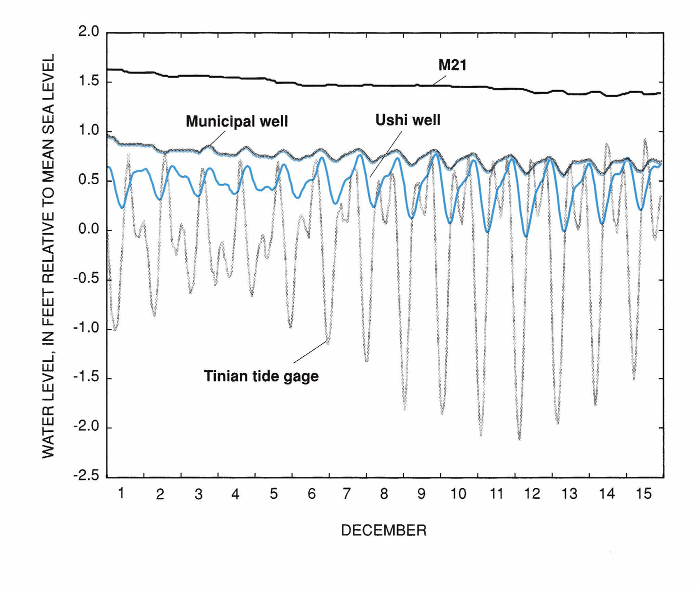

Figure 10. Selected ground-water levels and ocean level, Tinian, December 1–15, 1992.

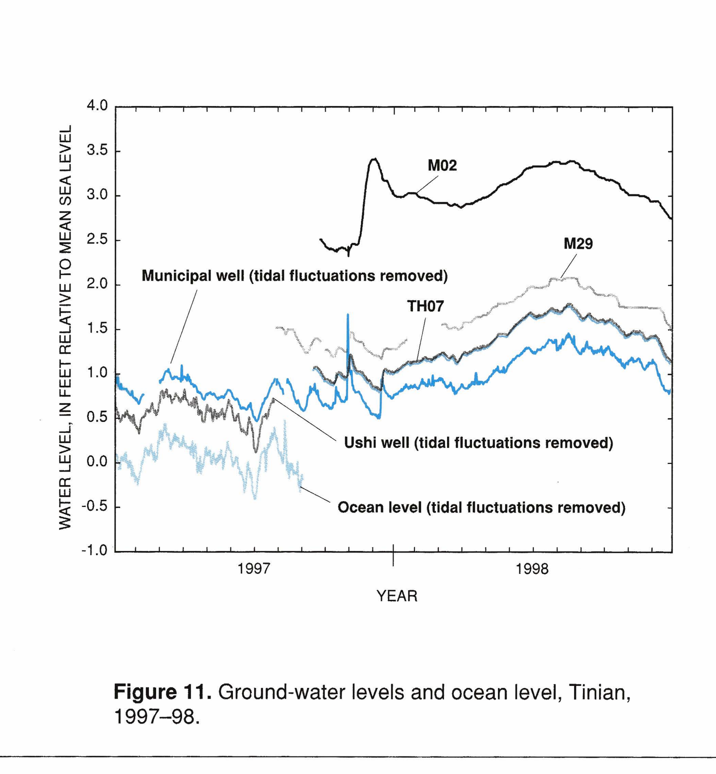

Figure 11. Ground-water levels and ocean level, Tinian, 1997–98.

GROUND-WATER RESOURCES OF TINIAN, COMMONWEALTH OF THE NORTHERN MARIANA ISLANDS

by

Stephen B. Gingerich and Daniel S. Yeatts

EVENHUIS

USFWS 2010

TERRESTRIAL ARTHROPOD SURVEYS ON PAGAN ISLAND, NORTHERN MARIANAS

Pacific Biological Survey

Final Report **November 2010**

Terrestrial Arthropod Surveys on Pagan Island, Northern Marianas

Neal L. Evenhuis, Lucius G. Eldredge, Keith T. Arakaki,
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Pacific Biological Survey, Bishop Museum,
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TABLE OF CONTENTS

EXECUTIVE SUMMARY

This report is part of the "Marianas Expedition Wildlife Survey 2010" (MEWS 2010), a U.S. Fish & Wildlife Service (USFWS) project funded by the Department of Defense - U.S. Marines and is tasked to gather natural resource information on fish and wildlife in the Mariana Islands. This information is required by federal regulations to properly determine the potential impacts that will occur due to the shifting of significant military resources from Okinawa to the Territory of Guam and the Commonwealth of the Northern Mariana Islands. As part of this military build-up, Pagan is under consideration as a live fire training area.

This report gives the results of a terrestrial arthropod survey conducted by USFWS and NAVPAC personnel on Pagan in the month of July 2010 and gives details on significant findings resulting from material collected on that survey. In addition, a full checklist of terrestrial arthropods known from Pagan Island is given based on the current survey material as well as previous published records. An appendix gives a full bibliography of articles dealing with Pagan arthropods.

Staff from the U.S. Fish and Wildlife Service, Pacific Islands Office, and the U.S. Navy conducted collections of terrestrial arthropods from 9-21 July 2010 using a variety of collecting methods including Malaise flight intercept traps, yellow water pan traps, pitfall traps, peanut butter traps for ants, aerial sweep netting, aquatic dip netting, aspirating, and hand collections.

Thousands of terrestrial arthropod specimens resulted from these collections, which were sorted by the collectors to order (to class for non-insects) and delivered to the Bishop Museum for identification. A team of entomologists at the Bishop Museum identified a total of 288 different taxa of terrestrial arthropods based on the survey, which included 228 new island records for Pagan (doubling the number of arthropods previously recorded from Pagan) bringing the total number of terrestrial arthropod species known from Pagan to 416. The full list of identified arthropods is given in Appendix II and includes all previously published terrestrial arthropod records for Pagan as well as the new records identified during this study.

To put the arthropod fauna into a proper historical context in order to better understand their possible biological status on the island (e.g., endemic, native, nonindigenous), a history of human habitation as well as previous collecting expeditions is given. The vast majority of identified terrestrial arthropods are most likely nonindigenous, having arrived on Pagan via a variety of mechanisms including transport by humans, supply shipments, and commerce. Verification of true status requires study of the known distributions and potential vagility of each species, which was outside the scope of this report.

Although the island has undergone numerous geophysical and human land use changes resulting in what we are calling a synanthropic arthropod fauna, there are still pockets of native arthropods that survive. Eight endemic species are recorded, three of them are new to science. In addition, one new genus was found.

The littoral zone has been a neglected area for previous collectors, and a number of new marine and littoral faunal records have resulted from collecting during this survey.

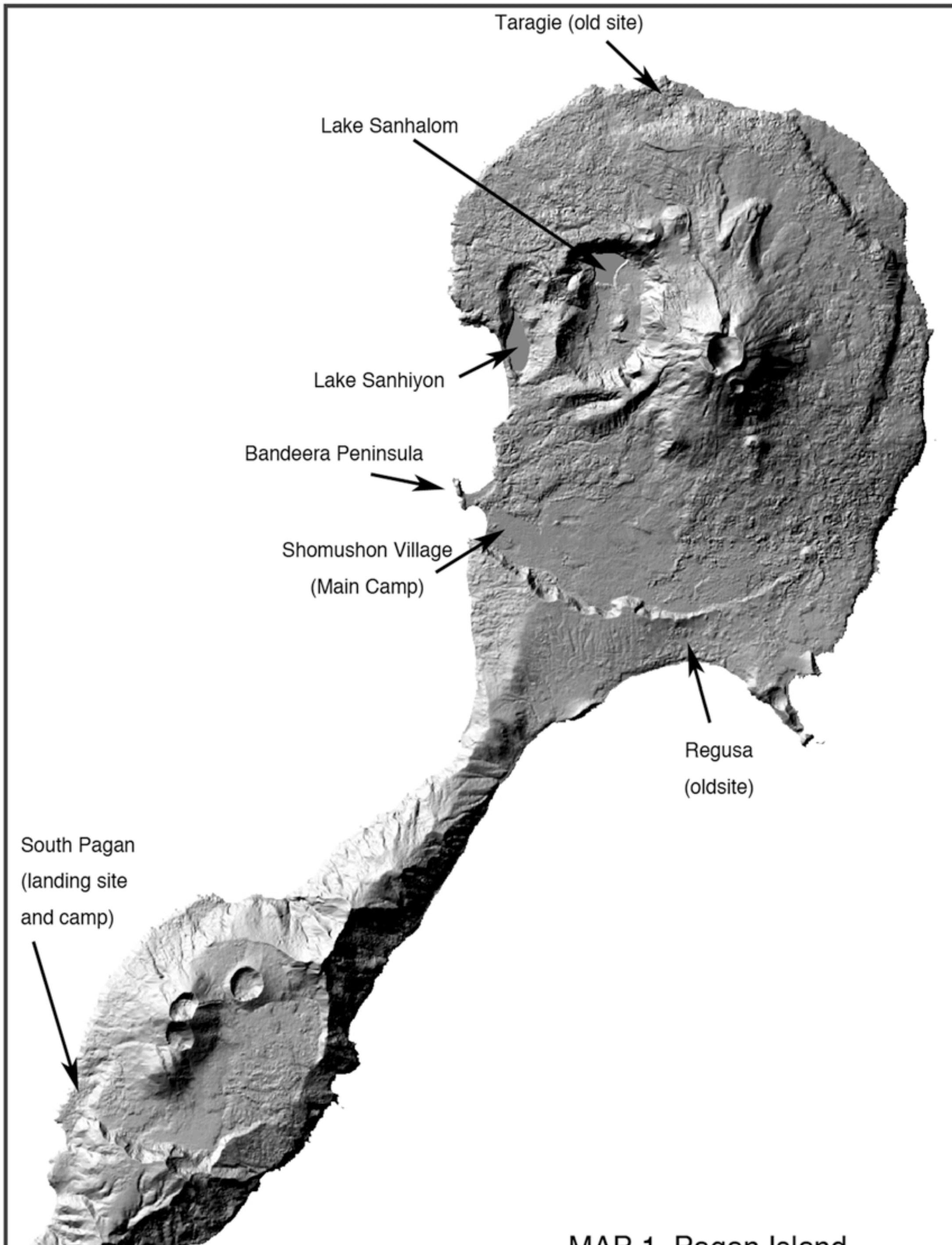
None of the arthropods identified are any threat to the megapode or fruit bat populations on the island. The crazy ant, *Anoplolepis gracilipes*, may pose a potential threat to food resources of the bat and megapodes if the populations on the island ever form what are called supercolonies. Their population levels now are large but not dangerous.

BACKGROUND

Pagan Island (Map 1) is the largest and most complex biologically and geographically among the northern islands of the Commonwealth of the Northern Mariana Islands (CNMI). The island was named "Pagan" by Jesuits who traveled through the Marianas in the 1600s. The name is one of the Christian names they gave to many of the islands in the Northern Marianas. Since its first visitation by western Europeans in 1695, Pagan has gone by many names including the following: Agan, Ile de Saint Ignace, Pagaon, Pagara, Pagon, Paygan, Pragan, Prajan, Pemplie de Volcans, Remplie de Volcaus, San Ignace, and Saint Ignace (Bryan, 1971).

It is an active volcanic island (18.10°N 145.76°E) approximately 320 kilometers north of Saipan. It contains three volcanic cones, the highest of which and most active, Mount Pagan in the northern part of the island, is 569.9 m [1870 ft] and whose last major eruption was in 1981, which had ash deposits and lava flows that covered or partially covered the village buildings and airfield and affected the shorelines of the two lakes in the northwestern portion of the island. A smaller eruption in 2006 deposited ash in the surrounding areas. The other two volcanoes are located in the southern portion of the island and last erupted approximately 150 years ago.

Fig. 1. Pagan viewing south, showing Lake Sanhiyon in foreground, separated from ocean by thick sand. Photo: Dan Polhemus.



MAP 1. Pagan Island

(showing some place names mentioned in the report)

There are two natural lakes on the island, both in the north part and both containing brackish water. They were formed approximately 200 years ago (Asakura *et al*., 1994). The outer lake (Laguna Sanhiyon) [Fig. 1] is separated from the ocean by an approximately 50-meter wide berm of sand. The inner lake (Laguna Sanhalom) [Fig. 2] at one time had a hot mineral spring (see newspaper feature article by Ronck, 1975 for photos and description), the surface portion of which disappeared after the eruption of Mount Pagan in 1981 (warm water still percolates into the lake from below the surface). Trusdell (2009) gives a concise summary of the geology of the island.

Fig. 2. Lake Sanhalom, Northern Pagan. Photo: Dan Polhemus.

GENERAL HISTORY

Because changes in ecosystems due to anthropogenic factors play a large part in the constituency of the vegetative and zoological composition of an island, we here present a short history of habitation and human activities on Pagan.

Human habitation has been intermittent on the island, owing primarily to factors such as volcanic eruptions and various commercial interests over time. Archeological surveys and linguistic research suggest that the Marianas were first colonized about 3500 years ago. Little archeology has been done on Pagan owing to few good sites remaining after volcanic eruptions and poor dating sources (e.g., there is no clay and pottery had to be imported from the southern islands) (Russell, 1998). Despite this, research on a site on the eastern coast of Pagan suggested it was occupied by 1300 C.E. (Egami & Saito, 1973).

After the Spanish explorer Magellan sailed through the area in 1521 on his famous circumnavigation of the world, Spain declared the archipelago as a royal possession. However, for the next 140 years the islands were virtually neglected as Spanish activities there were few. In 1668, a Jesuit mission was established on Guam and not long after its founding, priests began traveling northward from island to island in their attempts to convert the native Chamorros to Christianity. Seeing that the remote ventures to the islands to the north of their Guam base was becoming ineffectual in procuring efficient conversions, the Spanish began a program called the *reducción*, which relocated residents scattered on all the northern islands to one island: Saipan. The residents of Pagan were relocated to Saipan in 1697 and, except for the rare exploratory expeditions of the 19th century that sailed in to the area to make hydrographic studies, the island slipped into obscurity once again.

In 1865 a serious attempt to re-introduce residents to Pagan was initiated by American George Johnson, who brought 265 Carolinians to Pagan to produce copra. This adventure was short-lived, though, as all the Pagan residents were sent to Saipan in 1869. The reasons are unclear as to why the copra production was abandoned on Pagan but they could well have been economic (Russell, 1998) since the northern islands were too far removed from the economic center of Guam to sustain commercially viable operations.

In 1899 Germany purchased from Spain all the islands north of Guam, and their administration was headquartered on Saipan. The 1899 census by the Germans gave the population of Pagan then as 75 (Spennemann, 1999). In May 1901, Governor G. Fritz visited the northern islands and made observations on the general geology and volcanic activity (Fritz, 1902). Further observations, including those on the fauna and flora, were made by the Czech zoologist and parasitologist Stanislaus Prowazek (1913).

World War I saw a changeover of administration of the islands from Germany to the Japanese. In 1914, the islands of the northern Marianas became part of the Japanese Mandated South Seas Islands through action of the League of Nations. A number of Japanese scientists made expeditions during the 1930s and published accounts of the flora (e.g., Hosokawa, 1934), submarine topography (Tayama, 1936), volcanic geology (Tanakadate, 1940) as well as insects (see below for more details). During World War II, the Northern Marianas were of little strategic or tactical value except Pagan. The Japanese constructed an airfield on Pagan as well as associated troop barracks, storage bunkers for bombs and fuel, and pillboxes and air-raid shelters. Manning this base were over 2000 Japanese troops (Richard, 1957). After the surrender of the Japanese garrison in September 1945, the Japanese were returned home and the surviving Chamorros were all taken to Saipan due to extreme food shortages.

After World War II, the islands of the Marianas were administrated by the United States Trust Territory. Several field projects were carried out on the fauna and flora; and the military funded research on the geology. A small military contingent remained on the island to maintain the airfield (Corwin *et al*., 1957).

In 1948, Chamorros and Carolinians decided to start up commercial operations in the Northern Marianas again; and in 1951, 57 Chamorros were brought to Pagan to produce copra. Copra production waxed and waned and eventually was abandoned altogether by the 1970s; the remaining residents were maintained with supplies brought in from government-run "field trip" ships a few times a year. The volcanic eruption of Mount Pagan in 1981 forced the 53 residents of the island to flee to Saipan. The resultant lava flows and ash destroyed much of the vegetation of the northern part of the island and covered the airfield. The recent 2006 eruption again caused a significant amount of ash and lava to cover the northern portion of the island so that there is a conspicuous lack of vegetation and associated life forms in the immediate vicinity of the volcano.

PREVIOUS EXPEDITIONS TO PAGAN SURVEYING TERRESTRIAL ARTHROPODS

Little attention has been paid to Pagan with respect to the island's terrestrial invertebrate fauna. Most explorers who had visited Pagan had either looked upon it from the ship and made notes to charts, or upon landing, made only ethnological and geological observations or commented on the vertebrate fauna [large mammals such as pigs having been introduced to the island not long after Magellan's sail through the island chain in the 1500s (Rodda, 2009)].

Fig. 3. The first insect collector on Pagan. "Mariano" who accompanied Alfred Marche on his trip there in December 1887 (from Marche, 1982).

The first collection of insects was apparently made in 1887 by Antoine-Alfred Marche (1844–1898), a naturalist and ethnologist at the Musée de l'Homme in Paris. He had previously made trips to Africa, the Philippines, and Guam to do ethnology research and had published accounts of his travels there. His trip to the Marianas in 1887–1888 was to be his last. In Manila shortly after arriving, he hired a collector, Mariano (Fig. 3) and a cook and headed north to stop at various of the Mariana Islands. His account of his December 1887 stay on Pagan during his trip through the Marianas [translated into English in 1982 from the original (Marche, 1891) in a little-known French journal] gives a detailed description of the island and is accompanied by the first known photograph of Mount Pagan (Fig. 4) however, he says little of the biology of Pagan (Marche, 1982: 20):

> "On Pagan, there are only a few Carolinians settled there to harvest coconuts, which trade is carried on by Captain William. Hunting gave me meager results; birds are scarce; before the great typhoon of 1884, they were in far greater number. No mammal, except for some pigs and wild goats. Fresh water appears to be completely lacking on this island."

He concluded his report of Pagan by giving an account of the material he collected (Marche, 1982: 22):

> "Upon my return to Guam, I prepared and sent my second shipment which contained eleven objects for the Ethnographic Museum, about 200 skinned birds, 450 mollusks in alcohol, 300 skins, plus 500 insects in paper and in alcohol and about 100 species of plants with flowers and fruits."

Fig. 4. First known photograph of Mount Pagan, taken by Alfred Marche in 1887 (from Marche, 1982).

Although some of the birds he collected were studied by Oustalet (1895–1896), no one has apparently bothered to trace the current whereabouts or existence of his insect collections, which may still be in the Musée de l'Homme in Paris.

After Germany purchased the Marianas from Spain and began their governance, two surveys were conducted that made natural history observations: Fritz (1902) and Prowazek (1913). The latter gave a detailed report on the history, culture, and fauna and flora of the Marianas but gave sketchy remarks concerning arthropods. Prowazek (1913) discussed a number of species as occurring in the Marianas but does not specifically list species occurring on Pagan.

When the Japanese administered the Pacific islands acquired through the League of Nations, scientific expeditions were made in the 1930s to survey the natural history of their newly acquired possessions in the Pacific. One of these was the Esaki Micronesian Expeditions from 1936–1940, which resulted in a number of publications by specialists including descriptions of many new species and the first published records of arthropods from Pagan. Professor Teiso Esaki, entomologist at Fukuoka University, was in charge of entomological investigations for the Japanese administration of Micronesia before World War II. Almost 80 publications were generated from these surveys, although most dealt with islands other than the northern Marianas.

As part of these expeditions, the first collecting trip specifically to Pagan was made in April 1940 by Fukuoka University entomologist Keizo Yasumatsu (Fig. 5) and scientific records of arthropods from that trip were published in Yasumatsu (1940). It included few records as the publication was only meant to be a short narrative of the collecting trip. However, many other publications by Japanese colleagues on Pagan arthropods soon followed, mostly basing their results on material collected by Yasumatsu and his student Seiichiro Yoshimura during this trip in April 1940.

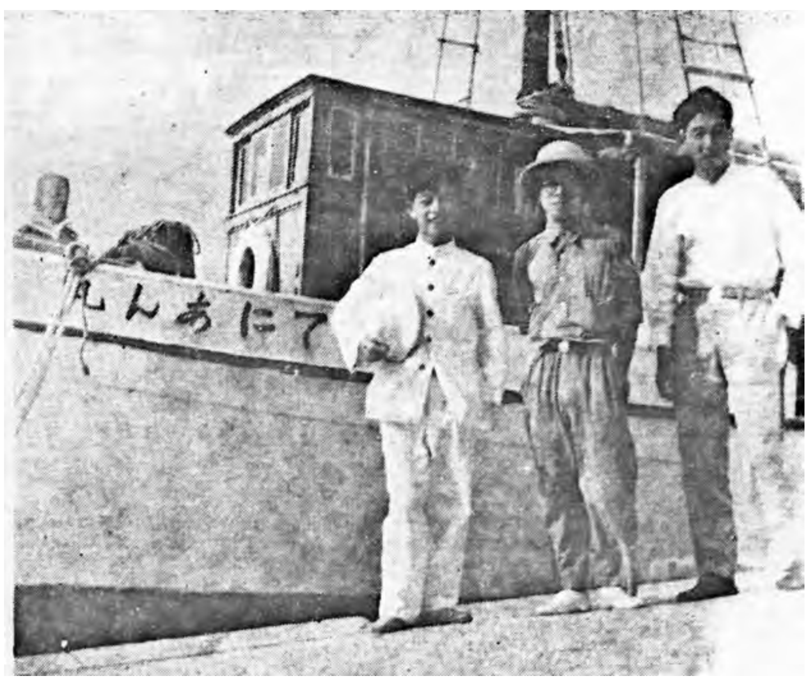


Fig. 5. Esaki Micronesian Expedition to Pagan, April 1940. Keizo Yasumatsu, center (from Yasumatsu, 1940).

In 1946, shortly after the end of World War II, the Pacific Science Board of the U.S. National Research Council was established. It was set up to "aid the scientists of America who wish to engage in scientific investigations for which there is a need in the Pacific area, to advise governmental and other agencies on scientific matters pertaining to the Pacific, and to further international cooperation in the field of Pacific science." The Pacific Science Board cooperated with the U.S. Navy in investigating certain problems that both felt were a priority for the Pacific area. One of these was finding ways to control insect and related pests in Micronesia. The Insect Control Committee for Micronesia (ISSM) was thus established and its priority research areas included research on the following pests: (1) the giant African snail; (2) the rhinoceros beetle; (3) the banana root borer; and (4) the Saipan coconut beetle (Bryan, 1949). The ICCM employed a staff entomologist, Daniel B. Langford, who made trips to Micronesian islands from October 1947 to October 1949. He only visited Pagan on a trip from 5–18 May 1948 that also included the islands of Anatahan, Alamagan, and Agrihan. It is not known how long he spent on Pagan and what if any arthropods he may have collected.

In 1953, the entomological work of the Pacific Science Board and the office of Naval Research were taken over by the Bishop Museum in Honolulu and with the funding assistance of two grants from the National Science Foundation, the series *Insects of Micronesia* was begun (Gressitt, 1954). The hundreds of resulting articles in 19 volumes offer to date the most detailed taxonomic accounts of insects occurring in Micronesia, and many of these include records and descriptions of arthropods from Pagan. The series was discontinued as a separate series by Bishop Museum in the 1990s but was turned over to the University of Guam, which continues to publish articles in the series within their journal *Micronesica*; the last of which was on lauxaniids (Sasakawa, 2009).

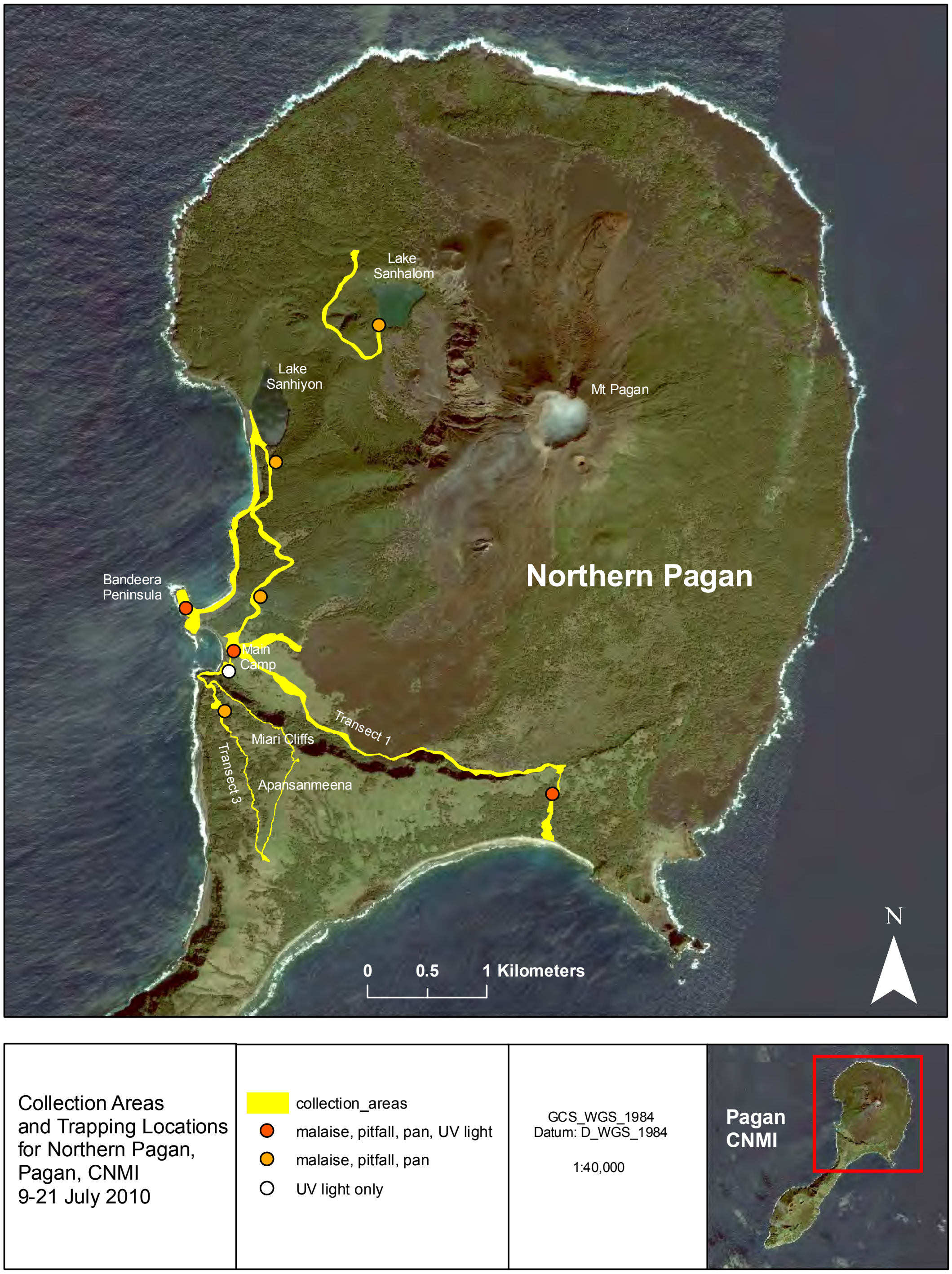
As part of the U.S. Army Corps of Engineers' "Post Hostilities Mapping Program" a geological survey was conducted of Pagan in the 1950s, the results of which were published in Corwin *et al*. (1957). Along with the detailed geological report and mapping, plants were listed and animals observed and discussed in the narrative. However, remarks on arthropods were brief:

> "More than a hundred species of insects, several spiders, two scorpions, two isopods, and a few worms, centipedes, and millipedes have been collected. Of these only a few may be classed as pests. Two species of flies are common and very annoying. Cockroaches and large beetles may do some damage to supplies. Mosquitoes are chiefly nocturnal varieties and are harmless. Stinging wasps are numerous in many groves of Casuarina trees. Although rarely fatal, the bites of the scorpions and one large variety of centipede may cause considerable discomfort" (Corwin *et a*l., 1957: 109).

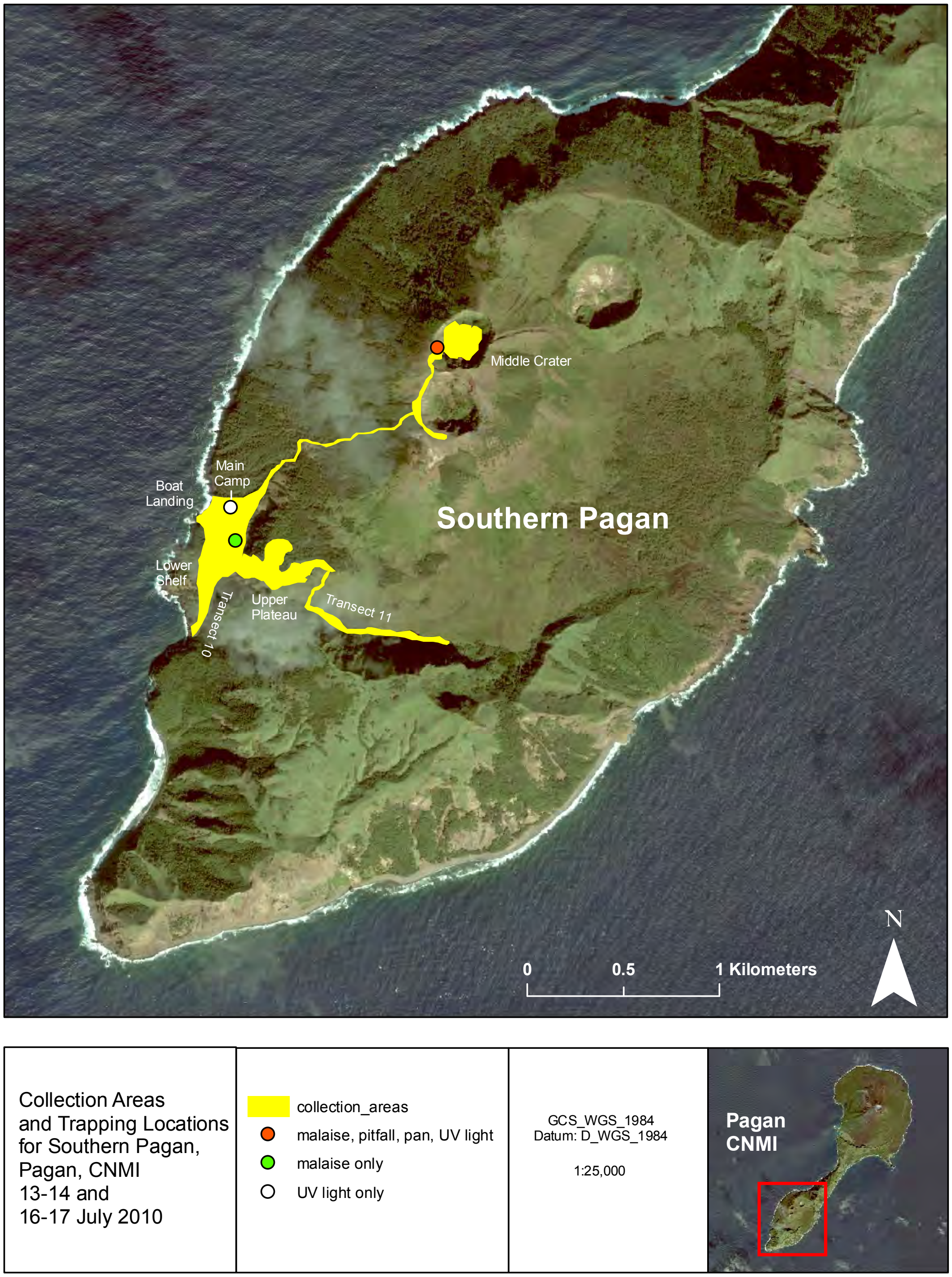
The Natural History Museum and Institute in Chiba, Japan conducted a biological expedition to the northern Marianas in 1992 and results were published in a single volume (Asakura & Furuki, 1994). This was the last formal expedition to Pagan to survey arthropods prior to the current survey. The volume contains dozens of articles on the results of this expedition and contains a checklist (Miyano, 1994) that forms the basis for the current checklist in this report.

Since then, Pagan has only had sporadic visits primarily for floristic or vertebrate surveys, or for geological concerns; with little work done on arthropods. One report

(Cruz *et al*., 2000) mentions insects being collected opportunistically on Pagan but no specific records were listed in the report.



Map 2. Collection sites on northern Pagan, 9-21 July 2010.
Colored dots are sites where traps were set.
Yellow lines indicate collecting while hiking.



Map 3. Collection sites on southern Pagan, 13–17 July 2010.
Dots are sites where traps were set.
Yellow lines indicate collecting while hiking.

CURRENT SURVEY AND LIST OF COLLECTING SITES

The current survey was conducted by three NAVPAC personnel (Cory Campora, Stephan Lee, Justin Fujimoto) and USFWS staff members (Christa Russell, Mike Richardson) from 6 to 21 July. A few specimens made prior to the main arthropod survey (collected by E. Wosh on 25 June [during a herpetological survey] on south Pagan) were also included in the identifications. Additionally, Dan Polhemus of USWFS (not a part of this survey contract) made a separate survey to assess the aquatic insect fauna on Pagan and the results of his survey are incorporated herein. Specimens were collected by hand and sweep net from a variety of localities, usually while hiking from one locality to another. However, the majority of specimens were collected through various trapping methods, which were set up at specific localities and these are indicated below. A total of 10 sites employed various trapping methods and are detailed below.

LIST OF COLLECTING SITES

Site 1 [= Campora field notes site 4] [Fig. 6]

Northern Pagan, Main Camp (old Shomushon village), near runway, 9 July 2010 and 16 July. Collectors: Mike Richardson, Christa Russell, Stephan Lee, Justin Fujimoto, Cory Campora. [GPS: 18.12346°N, 145.760640°E]
Traps:
Malaise: 1 trap (9–10; 16–17 July collecting period)
Pitfall traps: 5 traps (9–10; 16–17 July collecting period)
Blacklight: 1 trap (night of 9, 16 July collecting period)
Additional collecting methods employed: general collecting.

Site 2 [= Campora field notes site 6] [Fig. 7]
Northern Pagan, Lake Sanhalom (west side), 10 July 2010. Collectors: Mike Richardson, Christa Russell, Stephan Lee, Justin Fujimoto, Cory Campora. [GPS: 18.14814°N, 145.771950°E]
Traps:
Malaise: 1 trap (10–11 July collecting period)
Pitfall: 5 traps (10–11 July collecting period)
Pan traps: 5 traps (10–11 collecting period)
Additional collecting methods employed: aerial sweep netting, general collecting, aquatic dip netting.

Fig. 6. View of Collection Site 1: Main camp near Shomushon village, looking north.

Fig. 7. Collection Site 2: Lake Sanhalom, southwest side, showing Malaise trap and yellow pan traps

Site 3 [= Campora site 10] [Fig. 8]
Isthmus on Pagan, Trail along coast from main camp (megapode transect #3). 12 July. Collectors: Mike Richardson, Christa Russell, Stephan Lee, Justin Fujimoto, Cory Campora. [GPS: 18.11891°N, 145.759970°E]
Traps:
Malaise: 1 trap (12–13 July collecting period)
Pitfall: 5 traps (12–13 July collecting period)
Pan traps: 5 traps (12–13 collecting period)
Additional collecting methods employed: general collecting

Fig. 8. Collection site 3. Megapode transect #3 along west coast south from Main Camp, showing Malaise trap set up.

Site 4 [= Campora site 12] [Fig. 9]
Southern Pagan, South Camp area, southern end of island (megapode transect #10). 13 July 2010. Collectors: Mike Richardson, Christa Russell, Stephan Lee, Justin Fujimoto, Cory Campora. [GPS: 18.064313°N, 145.715226°E]
Traps:
Malaise: 1 trap (13–14 July collecting period)
Pitfall traps: 5 traps (13–14 July collecting period)
Blacklight: 1 trap (night of 13 July collecting period)
Additional collecting methods employed: general collecting, aerial sweep netting.

Fig. 9. Collection Site 4. Southern Pagan camp site. Traps were set nearby.

Site 5 [= Campora site 16] [Fig. 10]
Northern Pagan, Bandeera Peninsula. 15 July 2010. Collectors: Mike Richardson, Christa Russell, Stephan Lee, Justin Fujimoto, Cory Campora. [GPS: 18.126670°N, 145.756860°E]
Traps:
Malaise: 1 trap (15–16 July collecting period)
Pitfall: 5 traps (15–16 July collecting period)
Pan traps: 5 traps (15–16 collecting period)
Blacklight: 1 trap (night of 15 July collecting period)
Additional collecting methods employed: none.

Fig. 10. Collection Site 5. Top of Bandeera Peninsula, looking east toward an active Mount Pagan, showing Malaise trap in place.

Site 6

Southern Pagan, Main camp. 15–16 July 2010. Collectors: Mike Richardson, Christa Russell, Stephan Lee, Justin Fujimoto, Cory Campora. [GPS: 18.065892°N, 145.714867°E]

Traps:

Blacklight: 1 trap (night of 15 July collecting period)

Additional collecting methods employed: none.

Site 7 [Fig. 11]

Southern Pagan, Middle crater. 15–16 July 2010. Collectors: Mike Richardson, Christa Russell, Stephan Lee, Justin Fujimoto, Cory Campora. [GPS: 18.073481°N, 145.725095°E]

Traps:

Malaise: 1 trap (15–16 July collecting period)

Pitfall: 5 traps (15–16 July collecting period)

Additional collecting methods employed: aerial netting off of vegetation

Fig. 11. Collection Site 7. Southern Pagan, middle crater, showing Malaise trap in place.

Site 8

Northern Pagan, south of Lake Sanhiyon, Ironwood forest. 17–19 July 2010. Collectors: Mike Richardson, Stephan Lee, Justin Fujimoto. [GPS: 18.137694°N, 145.76903°E]

Traps:

Malaise: 1 trap (17–19 July collecting period)

Pan traps: 5 traps (17–19 collecting period)

Pitfall traps: 5 traps (17–19 July collecting period)

Additional collecting methods employed: aerial netting off of vegetation.

Site 9

Northern Pagan, Somushon village, north of motor pool. 17–18 July 2010. Collectors: Mike Richardson, Stephan Lee, Justin Fujimoto. [GPS: 18.127526°N, 145.762736°E]

Traps:

Malaise: 1 trap (17–18 July collecting period)

Pan traps: 5 traps (17–18 collecting period)

Additional collecting methods employed: aerial netting off of vegetation.

Site 10 [Fig. 12]
Eastern central Pagan, coconut grove. 20–21 July 2010. Collectors: Mike Richardson, Stephan Lee, Justin Fujimoto. [GPS: 18.112823°N, 145.785874°E]
Traps:
Malaise trap: 1 trap (20-21 July collecting period)
Pan traps: 5 traps (20–21 collecting period)
Additional collecting methods employed: aerial netting off of vegetation.

Fig. 12. Collection Site 10. Coconut grove on east side of island, showing Malaise trap in place.

SAMPLING METHODS

Collecting on Pagan was done with Malaise trapping, yellow water pan trapping, pitfall traps, ultra-violet light traps, and aerial sweep nets. Malaise traps, pan traps and pitfall traps were set up in various locations (see Maps 2, 3) to allow sampling in various vegetative habitats. The ultra-violet light trap was set up near the main camp to allow easy access during evening collecting. Aerial sweep netting and hand collecting were conducted along transects and trails as indicated in yellow on the maps.

Descriptions of some of the collecting methods employed during this survey include the following:

1. Malaise traps—Malaise traps are among the most productive samplers in terms of species richness and number of specimens captured. Flying insects approach the central panel of the trap and attempt to avoid it either by dropping to the ground or flying upward. Those flying upward (the vast majority) are funneled into the collecting head of the trap where they are killed. The collecting head is attached to the higher end of the trap. Insects caught at the top, are killed by drowning in a collecting canister of 95% ethanol. Those dropping to the ground can be collected in water pan traps.

2. Water pan traps—Shallow plastic pans (often yellow or white) are placed on the ground or in trees to sample arthropods. The pans are filled with water and a surfactant (soap solution) to allow trapped specimens to sink to the bottom of the pan and drown. They are attractive to flying insects in both open areas and forest canopy.

3. Pitfall traps—These consist of small plastic cups placed into the ground with the rim level with the surface. Pitfall traps collect most ground dwelling arthropods either through adventive encounters to the trap or by baits. Arthropods fall into the trap and a propylene glycol solution in the bottom of the cup kills the trapped arthropods.

4. Aerial nets—Aerial sweep nets with a fine mesh to collect smaller Diptera and Hymenoptera are used to sample arthropods on vegetation, leaf litter, littoral habits, beaches, and rocky intertidal reefs.

5. Hand collecting—Hand collecting, with or without the use of an aspirator, are used for collecting arthropods on specific species of plants and to collect arthropods that are difficult to collect using other techniques—such as those on craggy rock faces, in small holes and crevices or on muddy substrates.

6. UV light traps—Ultra-violet (UV) light traps are used to collect flying insects at night. Insects are attracted to the ultra-violet light reflecting off of a white sheet and are collected off the sheet by hand or aspirator. These are especially good for collecting night flying Lepidoptera (moths) as well as certain beetles and some aquatic Diptera.

7. *Peanut butter bait*—Spreading peanut butter on sticks or cards as a bait attracts both sugar-loving and oil-loving ants, which can easily be transferred to collecting containers. Peanut butter baiting was used sporadically during the survey.

SURVEY RESULTS

Out of thousands of specimens collected during this survey, some 288 species of terrestrial arthropods were identified [see quick summary in Table 1]. Previous to this survey, 188 species of arthropods were published as occurring on Pagan Island. The current survey brings the total known species to 416 and includes 228 new records to the island. A full list of arthropods previously known from the literature from Pagan and those identified during this survey is given in Appendix II.

Table 1. Quick Summary of Results of Identifications by Order
(orders in red are new order or class records to Pagan)

order or class	prev	this	total	new records
Acarina (mites, ticks)	12	3	15	**3**
Araneae (spiders)	11	36	43	**33**
Blattaria (roaches)	5	4	7	**2**
Chilopoda (centipedes)	1	2	2	**1**
Coleoptera (beetles)	23	41	57	**34**
Collembola (springtails)	4	6	9	**5**
Dermaptera (earwigs)	0	2	2	**2**
Diplopoda (millipedes)	0	2	2	**2**
Diptera (flies, gnats, midges)	21	69	82	**61**
Embiida (web spinners)	0	1	1	**1**
Hemiptera (true bugs)	20	12	31	**10**
Homoptera (aphids, scale insects)	16	7	20	**5**
Hymenoptera (wasps, bees, ants)	42	47	69	**25**
Isopoda (sow bugs, pill bugs)	2	1	2	**0**
Isoptera (termites)	0	1	1	**1**
Lepidoptera (moths, butterflies)	10	17	22	**12**
Mantodea (mantids)	1	1	1	**0**
Neuroptera (lacewings)	3	8	9	**6**
Odonata (dragonflies, damselflies)	4	3	4	**0**
Orthoptera (crickets, grasshoppers)	3	14	15	**12**
Phasmatodea (walking sticks)	1	0	1	**0**
Pseudoscorpionida (pseudoscorpions)	3	2	5	**2**
Psocoptera (book lice, bark lice)	1	8	9	**8**
Scorpionida (scorpions)	2	1	2	**0**
Siphonaptera (fleas)	1	0	1	**0**
Thysanoptera (thrips)	2	2	4	**2**
Thysanura (bristletails, silverfish)	0	1	1	**1**
totals	**188**	**288**	**416**	**228**

The current survey lists 5 new order records (Dermaptera, Diplopoda, Embiida, Isoptera, and Thysanura), 99 new family records, and 228 new species records for Pagan. We were able to identify most all of the material collected except for groups that entailed special preparation and taxonomic expertise (e.g., Acarina; Collembola; Homoptera [Coccoidea];

Thysanoptera). However, even in those groups, we were able to identify at least to family the larger and better-known taxa. Brief overviews of the orders of arthropods encountered are given below with reference made to the more common or interesting taxa. Significant finds are described in more detail in the next section.

Pagan shows a fairly normally composed arthropod community with most elements represented that would be expected given the amount of human activity that has taken place over its history; thus the island's fauna can be said to be primarily synanthropic with pockets of native populations still surviving. A fairly high proportion of the arthropod fauna are introduced or are native elements of widespread species. Despite the large number of introduced taxa, it is significant that there are 8 endemic arthropods that are known only from Pagan (5 previously described; 3 new undescribed endemic taxa found during this survey). Further study is needed to determine the relative health of these populations. A few of these previously recorded endemic species were re-collected during this survey, indicating that at least some still survive despite the human-induced perturbations and volcanic activity.

Some species previously recorded were not found in this survey and, in some cases, it could be a result of land use changes that currently do not support resources that would have otherwise been there to allow a organism to survive; or, more probable, that sampling was not done in enough areas to be able to re-collect these taxa. In addition, soil sampling and use of Berlese or Tullgren funnels were not employed on this project, which can help with obtaining microscopic soil and ground dwelling organisms such as pseudoscorpions, mites, springtails, and small beetles and immature stages of many holometabolous orders of insects.

A note on place-names

Many of the names on the labels of material collected by Yasumatsu in 1940 and published in subsequent papers by Japanese colleagues as well as other scientists are no longer used and their current equivalents are difficult to decipher since no one has tried to trace them previously and some localities do not exist any longer. Based on a manuscript list of names provided to one of us (LGE) by a Pagan resident in the 1970s and the report by Pangelinan & Kapileo (1970) comparing with the Japanese transliterations of these names by Yasumatsu and others, we here give a list of a few of the old names used by Yasumatsu and their current equivalents in the hopes it will help pinpoint collecting localities for future workers.

Old Yasumatsu Name	**Current Equivalent**	**General location (all North Pagan)**
Song-Song	Shomushon	Main village
Laguna	Laguna Sanhiyon	outer lake; also name of the village there
Regusa	Regusa, Rugusa Degusa	location on eastern coast; site of old Japanese hospital
Tarague, Darage	Taragie, Tarague	old village on N coast; archaeological site
Males, Malasu	Maras, Marasu	location on NW coast between Laguna Sanhiyon and Tarague
Abansantate	Apasanmeena	location near isthmus

TAXON ACCOUNTS

ACARINA (mites, ticks) [Fig. 13]

Fig. 13. *Pyemotes* bee mite. **New Island Record.** Photo: Wikipedia.

Few mites were collected in this survey, with those recovered being primarily in the pitfall traps. Only the ixodid (unverified identification but probably represents the cattle tick *Boophilus microplus)*, the bee mite (*Pyemotes* sp.; cf. Fig. 13) and an oribatid soil mite were recorded in this survey. Previous surveys (which involved mite specialists) recorded 12 species from Pagan. Further specialized collecting including soil samples and Berlese funnels and identification of properly prepared specimens should identify many more acari from the island. The *Pyemotes* mite was collected from a tenebrionid beetle, which had 30 or so specimens attached to its body. The mites were attached to the body under the wings and covered the thoracic and abdominal region.

ARANEAE (spiders) [Fig. 14]

Few spiders had been previously recorded from Pagan. The only publication on spiders from Pagan (Yoshida *et al.,* 1996) listed 11 species in 8 families. Collections from this survey significantly increased the known spider fauna with 33 new species records of taxa from the island bringing the number of species known from Pagan to 43 in 22 families. Most are common widespread species in the Pacific. One conspicuous spider, the common cane spider, *Heteropoda* sp. (Fig. 14) was found in numbers under fallen logs in a mixed forest in north Pagan. These spiders are free-living predators that do not spin webs. They naturally occur on the forest floor but sometimes enter buildings. They usually prey on ground dwelling insects such as cockroaches, crickets, and silverfish.

BLATTARIA (roaches)

Previous to this survey, five roaches had been recorded from Pagan. All are synanthropic species that are widespread with humans and commerce. This survey only found three species with one new record, the widespread Pacific beetle roach, *Diploptera dysticoides*. Unlike other roaches, beetle roaches are not normally found in buildings but instead prefer leaf litter and soil.

Fig. 14. *Heteropoda* sp. (Sparassidae) flushed out from under a log on Megapode Transect #3. **New Island Record.** Photo: Cory Campora.

CHILOPODA (centipedes)

Centipedes are fairly ubiquitous in faunal surveys and are another component of a synanthropic fauna. Previous narratives of Pagan mention “centipedes” (e.g., Corwin, 1957); and two taxa were recovered in this survey: an undetermined member of the Geophilomorpha, and a *Scolopendra* sp., a genus that contains some of the larger taxa of this group of arthropods. *Scolopendra* are commonly transported in shipping from island to island throughout the Pacific.

COLEOPTERA (beetles) [Fig. 15]

Beetles are among the most diverse groups of insects in the world and as such also are among the most diverse in faunal surveys of specific areas such as islands. Previous to this survey, 23 species were recorded from Pagan, all fairly widespread species. We identified 41 taxa collected on this survey, with 34 new records for the island, bringing the total number of beetles known from Pagan to 57. Of these, the following are new family records to the island: Aderidae, Anthribidae, Bostrichidae, Cleridae, Corylophidae, Laemophloeidae, Melyridae, Mordellidae, Nitidulidae, Platypodidae, Salpingidae, Silvanidae, and Staphylinidae. The vast majority of species identified during this survey are nonidigenous taxa. Some of the coccinellid species listed were probably introduced at one time to control aphids on crops (the beetle immatures are predaceous on aphids) when commercial agriculture was prevalent on the island.

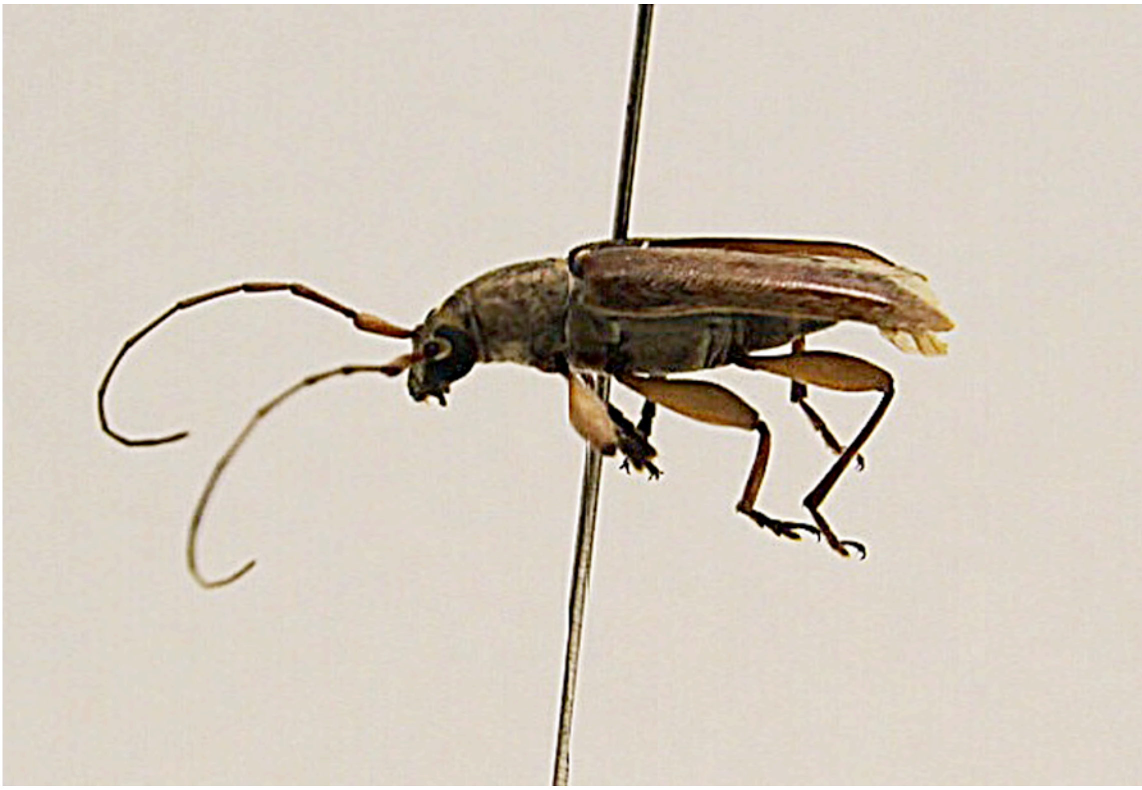


Fig. 15. The long-horned beetle, *Cersium unicolor unicolor* (Cerambycidae). Photo: Darcy Oishi.

COLLEMBOLA (springtails) [Fig. 16]

Springtails are often neglected in faunal surveys due to their small size but they are a major component of any ecosystem and are a potentially significant and biodiverse group of arthropods. Previous to this survey, only 4 species were recorded from Pagan including one endemic species (*Sira fuscana* Uchida, 1944) [Fig. 15]. Pan and pitfall traps recovered species of Collembola during this survey, and we were able to identify 6 species (including the endemic *Sira fuscana*) and confirm 5 new island records. Time needed to properly slide mount and key species was not enough to allow us to identify material to any finer resolution than what is represented in Appendix II, but we expect with future research and collecting, especially soil sampling utilizing Berlese funnels to extract arthropods, there will be additional new records for the island.

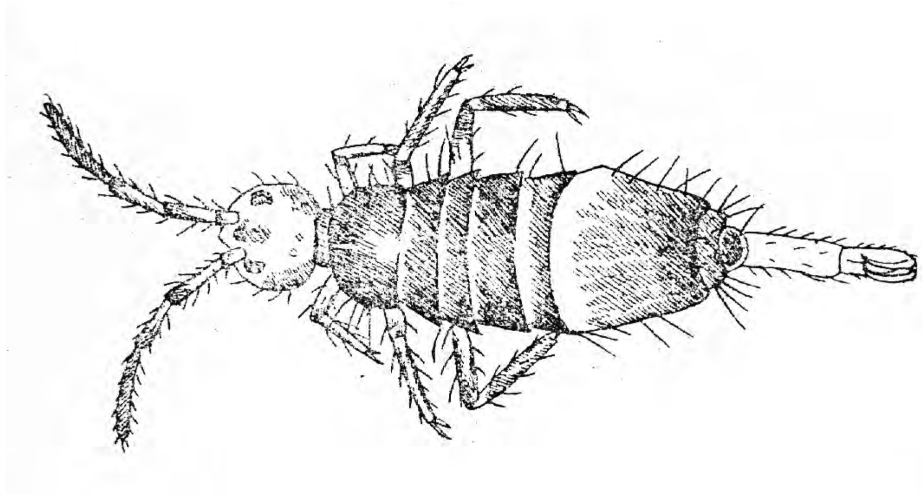


Fig. 16. *Sira fuscana* Uchida, an endemic springtail from Pagan (original illustration from Uchida, 1944).

DERMAPTERA (earwigs) [Fig. 17]

No earwigs were found previous to this study. Two species of earwigs were collected in this study and mark the first records of the order from Pagan. One species, *Euborellia stali* [Anisolabididae], is cosmopolitan and known from many localities in the western Pacific, Japan, and SE Asia as well as also being found in Africa and India. It was probably introduced to Pagan through the shipping of supplies. The other (Fig. 17) is as an undetermined labidiid, but is conspicuous with its huge caudal forceps. Earwigs are omnivores and will eat many types of organic matter.

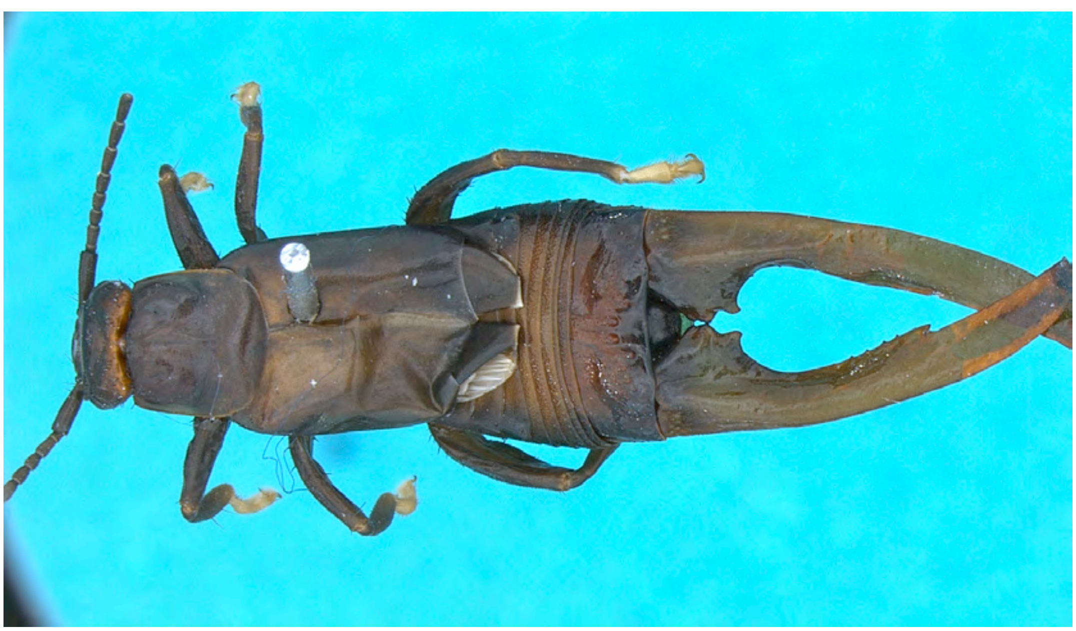


Fig. 17. An undetermined labidiid earwig from Pagan. Photo: Darcy Oishi.

DIPLOPODA (millipedes) [Fig. 18]

Fig. 18. *Trigoniulus corallinus*, the rusty millipede. **New Island Record**.

No millipedes had previously been recorded from Pagan. Two species are recorded for Pagan for the first time based on collection made during this survey. One species, the rusty millipede, *Trigoniulus corallinus* (Fig. 18), was collected and identified. The species is native to Thailand and Burma but has been introduced to many areas of the Pacific and Indian Ocean, and also the west Indies and North America (Shelley *et al*., 2006). The other species, *Harpaphes haydeniana* is the common yellow spotted garden millipede found throughout North America but not known previously from the west Pacific. Millipedes live in the soil and are detritovores and scavengers. Since this survey did not do soil sampling, we expect more species to be found through further more focused collecting for this group.

DIPTERA (flies, gnats, midges) [Figs. 19, 20]

Fig. 19. New genus and new species of hydrophorine dolichopodid fly from rocky shores on Pagan. **New Island Record**. Photo: Neal Evenhuis.

In previous surveys, flies were not well recorded with only 21 species in 10 families being published. We identified 69 different species of Diptera in 29 families that were collected during this survey, with 61 of them new records to Pagan, bringing the total number of Diptera species known from Pagan to 82. Of these, the following 19 families are new records to the island: Anthomyzidae, Canacidae (beach flies), Cecidomyiidae (gall midges), Ceratopogonidae (biting midges), Chamaemyiidae, Chironomidae (midges), Chloropidae (frit flies, eye gnats), Drosophilidae (pomace flies), Ephydridae (shore flies), Keroplatidae (predaceous gnats), Limoniidae (crane flies), Milichiidae, Nannodastidae, Phoridae (coffin flies), Platystomatidae, Psychodidae (moth flies), Sciaridae (fungus gnats), Sphaeroceridae (wrack flies), and Syrphidae (flower flies). The probable reason for the significantly large amount of new faunistic information on Diptera is that few workers bother to identify

Diptera outside of the nuisance, agricultural pest, or disease-causing species and leave the others undetermined. In this report, we have made a special effort to identify as many taxa as possible of this order to better show its true representation in the fauna.

Many of the species listed are synanthropic or associated with agricultural crops as pests or biological control agents. However, the discovery here of a few new taxa and the recollection of a previously recorded endemic taxon indicate that, despite the tremendous amount of human and volcanic impact on the island, there are still pockets of native species that are surviving. See below under SIGNIFICANT FINDINGS for more details on the new marine taxa found (e.g., Fig. 19).

Fig. 20. The ubiquitous *Musca sorbens*, also known as the dog dung fly. One of the most common and most annoying insects on Pagan.

EMBIIDA (web spinners)

No web spinners had been previously recorded from Pagan. The species collected and identified in this survey marks the first record of this species from Pagan. *Oligotoma humbertiana* is a common widespread species in southern and eastern Asia and the western Pacific that is commonly introduced in islands through transport of soils.

HEMIPTERA (true bugs)
(sometimes referred to as "Heteroptera" and encompassing the Homoptera)

The true bugs include many plant and agricultural pests, therefore attention has been paid to them in previous studies. Twenty taxa in 6 families had been identified from Pagan previous to this survey. Collections made here have resulted in identifications of 12 species, 10 of which are new records. Of these, one new undescribed endemic species was discovered by Dan Polhemus and is tentatively placed in the dumping-ground genus *Lygus* until further research can pinpoint its true generic status. Polhemus also identified marine Hemiptera, all new records to the island [see his report: Polhemus (2010) for details]. It is probable that collections made at the shore and in the littoral zone had not been conducted previously so all marine-associated arthropods were not recorded previous to this study. Many of the aquatic forms are widespread taxa with the ability to colonize tropical island habitats. With the material identified during this project, the total number of Hemiptera known from Pagan now stands at 31 species in 13 families.

HOMOPTERA (sucking bugs, aphids, scale insects)
(some have split this order into Auchenorrhyncha and Sternorhyncha)

Homopterans are primarily sap sucking bugs that include the aphids, mealybugs, and scale insects. Previous to this survey, 16 homopterans had been recorded in the literature. We identified 7 species, of which 5 are new records for the island. The total known homopteran fauna on Pagan is now 20 species. The new record of the leafhopper *Acertagallia* (Cicadellidae) may represent a recent introduction, as it was found in a number of collections so is well established on the island. As such, one would expect that it would have been collected previously. Leafhoppers are known to transmit plant diseases but nothing is known of the hosts or biology of the specimens collected during this study.

The collecting techniques utilized during this survey did not collect the scale insects and mealybugs that are normally easily identifiable. With regard to those smaller specimens that were found in the material collected, given the time available between delivery of material and the due date for the report, the resolution for some of the identifications of aphids and scale insects which normally require slide preparation and mounting for identification was not necessarily to species level.

HYMENOPTERA (wasps, bees, ants, parasitica) [Figs. 21, 22, 23, 32]

Hymenoptera included some of the most commonly encountered insects on the island. Previous to this survey, 42 species in 12 families had been identified and published. We have identified 47 species based on the current collections, of which 25 are new island records bringing the total hymenopteran fauna known on Pagan to 69 species in 20 families.

The social wasps recorded were no doubt introduced to the islands long ago as they are found in some of the earliest surveys. A few of these wasps will enter buildings and form nests [see Fig. 21], but others prefer to build nests in the forests which are closer to potential prey which they use to nourish their young.

Fig. 21. Social and solitary wasp nests (undetermined spp.) in abandoned building in Shomushon village. Photo: Jennifer Stauffler.

One of the most commonly collected groups during this survey were ants. They not only were tops in numbers of specimens but also had the highest species-diversity per family for any arthropod known from Pagan. This is no doubt due to the extreme success ants have at invading and colonizing new habitats such as islands.

Fig. 22. *Anoplolepis gracilipes*, the crazy ant, worker caste. Photo: Antweb.

Fig. 23. *Tetramorium smithi*, worker caste. **New Island Record**. Photo: Will Haines.

Previous to this study, 18 species of ants were known from Pagan, mainly all widespread species. During this survey, we identified 25 species including 10 new island records, bringing the total known number of ants from Pagan to 28. None of these species are endemic to the island and only a few may be native; the remainder are alien introductions. Their presence poses the greatest threat to the native ecosystem as many species are either predaceous on other invertebrates while others are seedeaters. Any unchecked predator can cause deleterious effects on plant and animals though depletion of resources and destruction of the flora. Although the most pervasive species found on Pagan and collected in huge numbers (hundreds) in some of the traps (see Fig. 32), the crazy ant, *Anoplolepis gracilipes* (Fig. 22), is not a major threat now but given its capacity to form what are called "supercolonies" in island ecosystem situations, it may become a serious pest [see SIGNIFICANT FINDINGS below for more information.

Five species of bees were previously recorded from Pagan (including one endemic megachilid bee) but were not as commonly collected during this survey (only 1 was identified, the common honeybee *Apis mellifera*). This may be due to competition with other more aggressive insects such as the social wasps and ants, both of which can either attack and overcome bees or outcompete for food resources or even deplete them.

ISOPODA (sow bugs, pill bugs, roly-polys, wood lice) [Fig. 24]

Two unnamed taxa of terrestrial isopods have previously been recorded from Pagan. During this survey, we collected one unnamed species in the family Armadillidae (pill bugs). These crustaceans are debris feeders and are harmless (they are not pestiferous or of any medical importance). They require moisture to survive so will be found in moist soil or under rocks or debris. They are nocturnal in feeding habits and not usually seen during the day unless an overabundance in populations causes them to expand into human habitations in search of moisture and shelter. Pill bugs are easily separated from their close cousins, the cosmopolitan wood lice (Porcellionidae) by the fact that pill bugs can roll up into a ball, wood lice cannot.

Fig. 24. Species of Armadillidae, a pill bug. Photo: Bugguide.net.

ISOPTERA (termites)

Termites are cosmopolitan but none had previously been recorded from Pagan. The discovery of the subterranean termite *Rhinotermes inopinatus* marks the first record of termites from Pagan. The species is a common widespread species found throughout the Pacific.

LEPIDOPTERA (moths, butterflies) [Figs. 25, 26]

Butterflies and moths are conspicuous insects in any arthropod survey. Although many lepidopterans are large and showy, there are not very many species known from Pagan. Previous to this study, only 10 species in 4 families had been published. During this study, using a variety of trapping methods as well as hand collecting, we have identified 17 species, of which 12 are new island records. The lepidopteran fauna on Pagan is now 22 species in 11 families.

Fig. 25. The widespread Blue-branded king crow butterfly, *Euploea eunice*, female. The caterpillars feed on fig trees. Photo: Darcy Oishi.

Fig. 26. The widespread (throughout the Pacific) Common eggfly butterfly, *Hypolimnas bolina*, female. Caterpillars feed on a variety of plants. **New Island Record.** Photo: Darcy Oishi.

One new record, the butterfly *Hypolimnas bolina* (Fig. 26), is a very widespread Pacific species, and it is unusual that is had not been recorded previously from Pagan. It was commonly collected during this survey, so has most likely been established on the island for some time.

Light trapping was conducted at two sites during this survey, which is the best method for collecting night flying insects such as moths. Despite the trapping, only a relatively few specimens of moths were identified during this survey, which most likely was as direct result of trapping during bad weather and/or bright, moonlit nights.

Some of the species identified based on collections made during this study (*Endotricha* sp., *Asymphrodes* sp., and *Anocharis* sp.) belong to large genera that are very diverse in the Pacific, so there is a high probability that eventual species-level identification may show that some are native or even endemic species on Pagan.

MANTODEA (mantids)

Only one species of praying mantis, *Orthodera burmeisteri*, a widespread species throughout the Pacific was previously recorded from Pagan and was also collected on this survey. Mantids are general predators and a natural component of most ecosystems. However, the species here was undoubtedly introduced long ago to the island. Mantids produce egg sacs (oothecae), a foam-like substance is produced by the mantid surrounding the eggs that hardens and protects the eggs while they are developing. These oothecae are usually attached to twigs or leaves.

Fig. 27. Ant lion larva from Pagan attacking crazy ant. Photo: Darcy Oishi.

NEUROPTERA (lacewings, ant lions) [Fig. 27]

Previous to this study, three species of neuropterans, two lacewings and an ant lion, were known from Pagan. Collections made during this study have identified 6 new species records including the first record of a brown lacewing (Hemerobiidae). In addition, larvae and adults of ant lions were collected, of which the adult was identified as a species of *Myrmeleon*, which is a new record to the island.

ODONATA (dragonflies, damselflies) [Fig. 28]

Four species of odonates were previously recorded from Pagan: one damselfly (*Ischnura aurora*) and three dragonflies. Three of the four species were recovered during this study. Dan Polhemus (pers. comm.) indicated that two of the three dragonflies may include a misidentification, so that there really may only be 3 species that occur from the island. A conspicuous absence on Pagan is the widespread and long-distance flier, *Pantala flavescens*. It occurs on most Pacific islands and is known to fly more than 1500 km over oceans to get from one freshwater source to another. The species is known from other islands in the Marianas but has not been seen on Pagan.

Fig. 28. The dragonfly *Diplacodes bipunctata*, male, from American Samoa. Photo: Dan Polhemus.

ORTHOPTERA (crickets, grasshoppers) [Figs. 29, 30]

Only three orthopterans were previously recorded from Pagan prior to this survey. Based on collections made during this project, 15 taxa have been identified including 14 new records. These include six acridids (grasshoppers), two katydids, three gryllids (crickets), two tetrigid grasshoppers, and the rare ant inquiline, *Myrmecophilus leei*. See below under SIGNIFICANT FINDINGS for more details on this last species.

Fig. 29. Unidentified tetrigid grasshopper. **New Island Record.** Photo: Darcy Oishi

Fig. 30. The ant inquiline, *Myrmecophila leei*. **New Island Record.** Photo: Neal Evenhuis

PHASMATODEA (walking sticks, stick insects)

One species of stick insect, the widespread *Acanthograeffea denticulata*, was previously recorded from Pagan. No collections of this or any other stick insects were made during this survey, but we expect the species still exists. It is known as a pest of coconut and coconut groves are abundant on Pagan, so it should still be there. This is an introduced insect that has been on the island for quite a long time. It was first recorded by Yasumatsu (1940) from collections made on Pagan in April 1940.

PSEUDOSCORPIONIDA (pseudoscorpions)

Pseudoscorpions are tiny (usually no more than 2 mm in length) arthropods that live in leaf litter and under tree bark where they prey on microscopic invertebrates. Three species had previously been recorded from Pagan (all taken from soil samples). Two species were identified during this survey, both new records for the island. Pseudoscorpions are not commonly found on tropical islands so the finding of all these different species on Pagan is notable. Further research should be carried out to determine why.

PSOCOPTERA (book lice, bark lice)

Bark lice are common forest dwellers where they are found in leaf litter or under decaying bark of trunks, logs, or twigs. One species, *Caecilius analis* was previously recorded (Thornton, 1981) but not collected during this survey. However, eight other species were identified from collections made during this survey, which are all new records for the island. As these species are a common and diverse group on other Pacific islands, we believe further more rigorous collecting focusing on this group should produce more species records from Pagan.

SCORPIONIDA (scorpions) [Fig. 31]

Previous records report two species of scorpions (one unnamed) from Pagan. One of these two species, *Liocheles australasiae* (Fig. 31) was found in one of the craters on south Pagan and identified during this survey. It is a small (ca. 2 cm long), common and widespread species throughout the Pacific islands. The sting of scorpions can be painful in some species but is rarely fatal. The sting of *Liocheles australasiae* is no worse than a bee sting. The paucity of material of collected during this survey despite the numerous pitfall traps throughout the island lends support to the presumption that their presence is very rare and as such they pose no threat or danger to humans or other animals on Pagan.

Fig. 31. The scorpion, *Liocheles australasiae*, commonly found throughout the Pacific. Approximately 2 cm long. Photo: Ryo Kenzaki.

SIPHONAPTERA (fleas)

The only known flea recorded from Pagan is the cat flea. It was not collected on this survey, but feral cats still abound on the island and it is presumed that the associated fleas still occur there as well.

THYSANOPTERA (thrips)

Two species of thrips were previously recorded from Pagan. Two thrips were found in the material collected but only one could be identified to species level due to time constraints. More specimens should be expected, as thrips are ubiquitous arthropods in all island faunas. Specialized collecting techniques focusing directly on host plants may be necessary to secure specimens for study. Thrips are known to be pests on crops. It is not known whether or not the two species previously recorded or the one collected in this study are pestiferous.

THYSANURA (bristletails, silverfish)

Silverfish are ubiquitous creatures usually associated with human habitation. They are detritus feeders and are pests in offices and libraries where they feed on paper.

SIGNIFICANT FINDINGS

Invasive species

HYMENOPTERA: FORMICIDAE
ANOPLOLEPIS GRACILIPES (SMITH, 1857) [Figs. 22, 32]

Probably the most prevalent arthropod in the survey is the crazy ant, *Anoplolepis gracilipes*. This highly invasive species is found worldwide and in some places where it has become introduced (e.g., Christmas Island in the Indian Ocean), it forms supercolonies (Abbott, 2006). These are multiple colonies with queens but no competition or aggravated behavior takes place between colonies allowing high densities of the ants in small areas where they can devastate plant and invertebrate biota to use as food resources for the burgeoning nests. No supercolonies were observed on Pagan; however, the high levels of abundance of the ants in pitfall and pan traps (e.g., Fig. 32) may be an indicator that this species may eventually form a supercolony on Pagan.

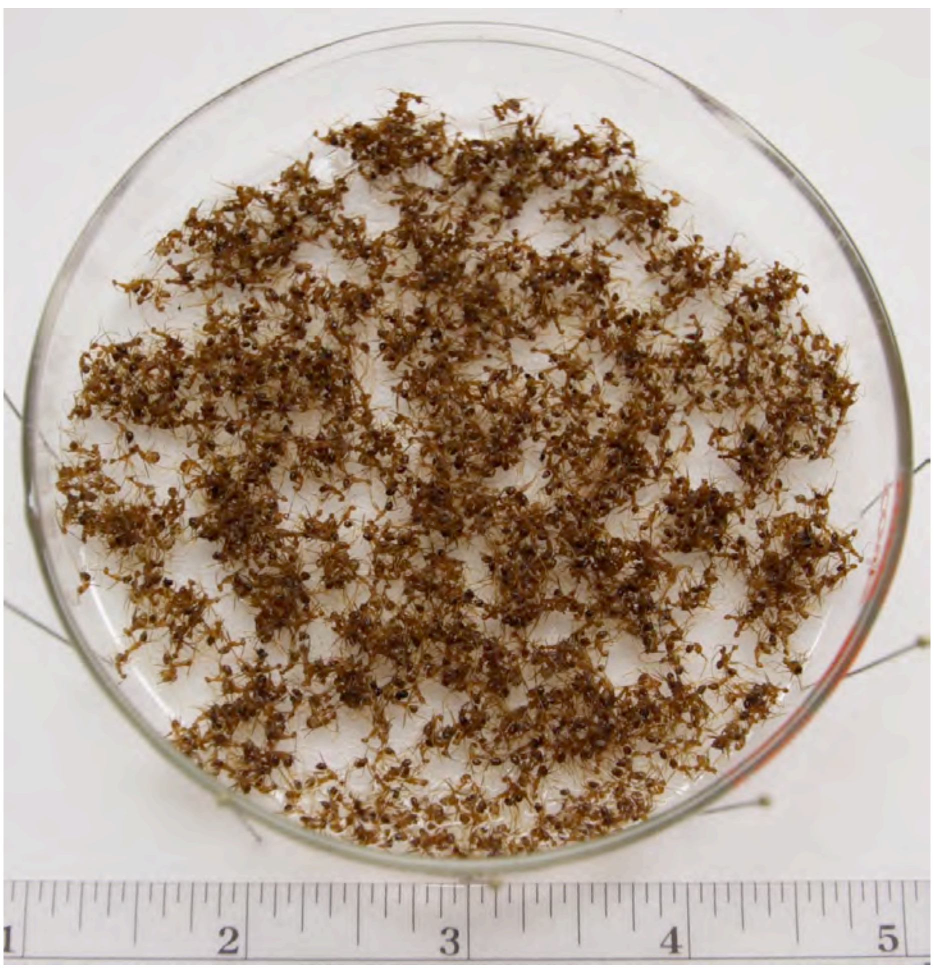


Fig. 32. Single sample of the crazy ant, *Anoplolepis gracilipes*, collected from a pitfall trap on Pagan. Photo: Darcy Oishi.

Selected Rare, New, or Unusual Species

DIPTERA: DOLICHOPODIDAE
HYDROPHORINAE - NEW GENUS, NEW SPECIES [Fig. 19]

A new genus and species of hydrophorine marine dolichopodid fly was collected off rocks on the west coast of Pagan. This is the first record for Pagan of this new taxon, which is otherwise known only from Guam. It should also occur on the islands between Guam and Pagan but have yet to be collected. Recent collections on Saipan by Dan Polhemus in September 2010 did not find any.

This taxon is found along rocky shores in the splash zone (Fig. 33). It is predaceous on other small invertebrates both as immatures and adults. Immatures were not found but should be found in small rock holes and crevices in association with algae and other littoral invertebrate organisms.

Fig. 33. Rocky shoreline on south side of Bandeera peninsula where a new genus of marine dolichopodid flies was collected. Photo: Dan Polhemus.

ORTHOPTERA: MYRMECOPHILIDAE
MYRMECOPHILA LEEI KISTNER & CHONG 2007 [FIG. 30]

This rare and unusual creature is an inquiline in ant nests. It was found associated with *Anoplolepis* on the south portion of Pagan and is the first record of this family from the island. It appearance here on Pagan is unusual in that, previous to this survey, it was originally described and known only from mainland Malaysia. It is most likely that this is much more widespread than previously known but has been neglected in previous collections because of its superficial resemblance to immature cockroaches. Samples from collecting on other areas between SE Asia and Pagan should be checked for this interesting ant inquiline.

THREATS TO FRUIT BATS OR THE MEGAPODE FAUNA

No direct threats to either megapodes or the fruit bat were found in this survey. Theoretically, predator and parasitic arthropods that deplete food resources may have an indirect affect on populations, but there is no evidence to suggest this has or will happen in the near future by any of the arthropods identified in this survey.

ACKNOWLEDGMENTS

The staff of the library and archives of the Bishop Museum and Hamilton Library at the University of Hawaii at Manoa assisted with obtaining some of the literature. Al Samuelson (beetles) and Kelly Miller (embiids) kindly assisted with identifications. Dan Polhemus allowed use of information from his aquatic insect survey report in this overall arthropod report. Maps 2 and 3 were prepared by Cory Campora. Many of the photos used in this report were kindly provided by Christa Russell, Cory Campora, and Dan Polhemus. Eiko Lynch assisted with transliterating the 1940 Yasumatsu localities. We especially acknowledge the efforts of the collectors of this survey, Christa Russell, Mike Richardson, Cory Campora, Stephan Lee, and Justin Fujimoto. Neither erupting volcanoes, sweltering heat during "death marches" across the island, charging bulls, constant companionship of "overly attentive" flies, thousands of ants billowing out of nests, nor spam, spam, and even more spam did not deter them from their goal of making an extensive and successful survey of the island of Pagan in only a few days.

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APPENDICES

APPENDIX I.
BIBLIOGRAPHY OF PAGAN TERRESTRIAL ARTHROPODS

The following is a complete list of all known publications specifically listing Pagan terrestrial arthropods including articles that mention arthropods as occurring on the island but without a scientific name. Many more articles list terrestrial arthropods with a low geographical resolution of only "Marianas" or "Northern Marianas". If those articles do not specifically mention Pagan, they are not included below.

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APPENDIX II. CHECKLIST OF PAGAN ARTHROPODS

(taxa in italics are synonyms or misidentifications [that appeared in the literature] of current valid names)

Order/Family	Taxon*	Prev. Publ.	This Study
ACARINA (mites, ticks)			
Ameroseiidae	Ameroseius sp. 2	x	
Eviphididae	Eximiris sp.	x	
Ixodidae	prob. Boophilus microplus		x
Laelapidae	Hypoaspis sp. 1	x	
	Hypoaspis sp. 2	x	
Ologamasidae	Gamasiphis sp. 1	x	
	Gamasiphis sp. 2	x	
Oribatidae	Gen. sp.		x
Podocinidae	Podocinum jamaicense Evans & Hyatt, 1957	x	
Pyemotidae	Pyemotes sp.		x
Rhodacaridae	Rhodacarus sp.	x	
Uropodidae	Metagynella sp. A	x	
	Trigonuropoda sp. B	x	
	Trigonuropoda sp. D	x	
	Uroobovella sp. C	x	
ARANEAE (spiders)			
Anyphaenidae	Gen. sp.		x
Araneidae	Argiope appensa (Walckenaer, 1841)	x	x
	Argiope sp. 2	x	
	Neoscona sp.	x	x
	Neoscona theisi (Walckenaer, 1842)		x
Clubionidae	Gen. sp. 1	x	x
	Gen. sp. 2		x
	Gen. sp. 3		x
Corinnidae	Gen. sp.		x
Gnaphosidae	Gen. sp. 1		x
	Gen. sp. 2		x
Linyphiidae	Gen. sp.		x
Liocranidae	Apostenus sp.		x
Lycosidae	Gen. sp.		x
	Pardosa sp.	x	
	Schizocosa sp. 1		x
	Schizocosa sp. 2		x
	Schizocosa sp. 3		x
Miturgidae	Cheiracanthium sp.		x
Nesticidae	Gen. sp. 1		x
	Gen. sp. 2		x
Ooponidae	Gamasomorpha sp.	x	
Pholcidae	Gen. sp.	x	
Pisauridae	Dolomedes sp.		x
Salticidae	Athamas whitmeei Pickard-Cambridge, 1877		x
	Hasarius adansoni Savigny & Audouin, 1825		x
	Plexippus sp. 1	x	x
	Plexippus sp. 2		x

Order/Family	Taxon*	Prev. Publ.	This Study
ARANEAE (spiders) [continued]			
Salticidae	Plexippus paykulli (Audouin, 1826)		x
	Sassacus sp.		x
	Thorelliola ensifera (Thorell, 1877)		x
Scytodidae	Scytodes sp.	x	
Sparassidae	Heteropoda sp.		x
	Olios sp.		x
Tengellidae	Gen. sp.		x
Tetragnathidae	Gen. sp.		x
Theridiidae	Argyrodes sp.	x	
	Coleosoma floridanum Banks, 1900	x	
Thomisidae	Thomisius sp.		x
	Gen. sp.		x
Titanoecidae	Gen. sp.		x
	Titanoeca? sp.		x
Zodariidae	Zodarion? sp.		x
BLATTARIA (roaches)			
Blaberidae	Diploptera dytiscoides (Serville, 1838)		x
Blatellidae	Blatella lituricollis (Walker, 1868)	x	
	Onychostylus notulatus (Stål, 1861)	x	
Blattidae	Periplaneta americana (Linnaeus, 1758)	x	x
	Periplaneta australasiae (Fabricius, 1775)	x	x
Pycnoscelidae	Pycnoscelus indicus (Fabricius, 1775)	x	
	Pycnoscelus surinamensis (Linnaeus, 1758)		x
CHILOPODA (centipedes)			
Scolopendridae	Scolopendra? sp. *"centipede"*	x	x
	Geophilomorpha gen. sp.		x
COLEOPTERA (beetles)			
Aderidae	Aderus sp.		x
Anthribidae	Araecerus fasciculatus (De Geer, 1775)		x
	Araecerus vieillardi (Montrouzier, 1860)		x
Bostrichidae	Xylopsocus capucinus (Fabricius, 1787)		x
	Xylothrips flavipes (Illiger, 1801)		x
Buprestidae	Agrilus auriventris Saunders, 1873	x	
Carabidae	Agadroma sp.		x
	Gnathaphanus licinoides Hope, 1842	x	x
	Stenolophus smaragdulus (Fabricius, 1798)	x	
Cerambycidae	Ceresium unicolor unicolor (Fabricius)		x
	Micronesiella mariana (Gressitt, 1956) *Sciadella mariana*	x	
	Phloeopsis meridiana (Ohbayashi, 1941) *Sciadella meridiana*	x	
	Prosoplus marianarum Aurivillus, 1908	x	
Chrysomelidae	Brontispa mariana Spaeth, 1937 *Planispa castaneipennis* Chujo, 1937	x	
	Gen. sp.		x

Order/Family	Taxon*	Prev. Publ.	This Study
COLEOPTERA (beetles) [continued]			
Cleridae	Necrobia rufipes (De Geer, 1775)		x
Coccinellidae	Coleophora inaequalis (Fabricius, 1775)	x	x
	Cryptolaemus montrouzieri Mulsant, 1853	x	
	Menochilus sexmaculatus (Fabricius, 1781)		x
	Nephus roepkei (Fluiter, 1938)		x
	Telsimia nitida Chapin, 1926	x	
Corylophidae	Sericoderus sp.		x
Curculionidae	Camptorrhinus dorsalis (Boisduval, 1835)	x	x
	Curculio sp.		x
	Deretiosus ficae Zimmerman, 1942		x
	Memectetorus cf. setulosus (Boheman, 1859)		x
	Microcryptorhynchus "sp. 2"	x	
	Myllocerus sp.		x
	Rhabdocnemis obscura (Boisduval, 1835)	x	
Dermestidae	Dermestes ater De Geer, 1774	x	x
Elateridae	Conoderus pallipes (Eschscholtz, 1829)	x	x
	Lacon modestus (Boisduval, 1835)		x
	Prodorasterius sp.	x	
	Simodactylus cinnamomeus (Boisduval, 1835)	x	
Endomychidae	Trochoideus desjardinsi Guérin-Méneville, 1857	x	
Laemophloeidae	Laemophloeus sp. nr. minutus		x
Melyridae	Gen. sp.		x
Mordellidae	Dellamora castanea (Boheman, 1858)		x
Nitidulidae	Carpophilus davidsoni Dobson, 1952		x
	Carpophilus sp. nr. davidsoni?		x
	Carpophilus humeralis (Fabricius, 1798)		x
	Carpophilus dimidiatus (Fabricius, 1792)		x
	Carpophilus sp.		x
Platypodidae	Phylloplatypus pandani Kato, 1998		x
Salpingidae	Prostomiinae, gen. sp.		x
Scarabaeidae	Adoretus sinicus Burmeister, 1854	x	x
	Aphodius lividus (Olivier, 1789)	x	x
Scolytidae	Ericryphalus sylvicola (Perkins, 1900)	x	
	Hypothenemus birmanus (Eichhoff, 1878)		x
	Hypothenemus eruditus Westwood, 1836		x
Silvanidae	Cryptamorpha desjardinsi (Guérin-Méneville, 1844)		x
	Silvanus nr. unidentatus (Fabricius, 1792)		x
Staphylinidae	Egadroma sp.		x
Tenebrionidae	Derosphaerus rotundicollis (Castlenau, 1840)		x
	Gonocephalum adpressiforme Kaszab, 1951 *Gonocephalum* sp.	x	x
	Gonocephalum incisum Blanchard, 1853		x
	Palorus papuanus Kaszab, 1939	x	
COLLEMBOLA (springtails)			
Entomobryidae	Gen. sp.		x
	Sira fuscana Uchida, 1944	x	x
Isotomidae	Gen. sp. 1		x

Order/Family	**Taxon***	**Prev. Publ.**	**This Study**
COLLEMBOLA (springtails) [continued]			
Isotomidae	Gen. sp. 2		x
Neelidae	Neelus minimus (Willem, 1900)	x	
Poduridae	Gen. sp.		x
Sminthuridae	Cyphoderus albinus Nicolet, 1841	x	
	Sminthurides sp.		x
	Sphaeridia pumilis (Krausbauer, 1891)	x	
DERMAPTERA (earwigs)			
Anisolabididae	Euborellia stali (Dohrn, 1864)		x
Labidiidae	Gen. sp.		x
DIPLOPODA (millipedes)			
Trigoniulidae	Trigoniulus corallinus (Gervais, 1847)		x
Xystodesmatidae	Harpaphe haydeniana (Wood, 1864)		x
DIPTERA (flies, gnats, midges)			
Agromyzidae	**Japanagromyza eucalytpi paganensis Spencer, 1963**	x	
	Japanagromyza sp.		x
	Liriomyza nr. brassicae (Riley, 1885)		x
	Melanagromyza atomella Malloch, 1914	x	
	Pseudonapomyza spicata (Malloch, 1914)		x
Anthomyzidae	Amalygdops sp.		x
Calliphoridae	Chrysomya megacephala (Fabricius, 1794)	x	x
	Chrysomya rufifacies (Macquart, 1843)	x	x
	Hemipyrellia tagaliana (Bigot, 1877)		x
Canacidae	Nocticanace peculiaris Malloch, 1933		x
Cecidomyiidae	Cecidomyiinae Gen. sp.		x
	Lestremia sp.		x
Ceratopogonidae	Dasyhelea sp. A		x
	Dasyhelea sp. B		x
	Dasyhelea sp. C		x
	Forcipomyia sp.		x
Chamaemyiidae	Leucopis sp.		x
Chironomidae	Chironomus longilobus (Kieffer, 1916)		x
	Thalassomyia maritima Wirth, 1947		x
Chloropidae	Cadrema pallida (Loew, 1865)		x
	Gen. sp.		x
	Siphunculina nitidissima Kanmiya, 1982		x
Culicidae	Aedes albopictus (Skuse, 1894)	x	x
	Aedes nocturnus (Theobald, 1903)		x
	Aedes saipanensis Stone, 1945		x
	Anopheles subpictus indefinitus (Ludlow, 1904)		x
	Culex annulirostris marianae Bohart & Ingram, 1946	x	
Dolichopodidae	Chrysosoma mariana Bickel, 1994	x	
	Chrysotus sp.		x
	Krakatauia micronesiana Bickel, 1994		x
	Hydrophorinae - New gen. n. sp.		x
	Tachytrechus sp.		x

Order/Family	**Taxon***	**Prev. Publ.**	**This Study**
DIPTERA (flies, gnats, midges) [continued]			
Dolichopodidae	Thinophilus sp.		x
	Plagiozopelma flavipodex (Becker, 1922)		x
	Sympycninae - New gen. n. sp.		x
Drosophilidae	Drosophila ananassae Doleschall, 1858		x
	Leucophenga nigriventris (Macquart, 1843)		x
Ephydridae	Allotrichoma sp.		x
	Atissa antennalis Aldrich, 1931		x
	Hecamedoides sp.		x
	Paralimna fusca Bock, 1988		x
	Paralimna lineata de Meijere, 1908		x
	Scatella septempunctata Malloch, 1933		x
	Zeros sp.		x
Keroplatidae	**Neoplatyura n. sp.**		x
Lauxaniidae	Homoneura acrostichalis (de Meijere, 1915)	x	x
	Homononeura sp.		x
Limoniidae	Dicranomyia basifusca Alexander, 1919		x
	Dicranomyia obesula Edwards, 1927		x
	Dicranomyia pontophila (Tokunaga, 1940)		x
Lonchaeidae	Lamprolonchaea sp.	x	x
	Gen. sp.		
	Lonchaea sp.		x
Milichiidae	Desmometopa gressitti Sabrosky, 1983		x
	Desmometopa tarsalis Loew, 1866		x
	Milichiella lactiepennis (Loew, 1865)		x
Muscidae	Atherigona orientalis Schiner, 1858	x	x
	Atherigona excisa (Thomson)		
	Haematobia exigua (de Meijere, 1903)		x
	Musca domestica Linnaeus, 1758	x	
	Musca sorbens Wiedemann, 1830	x	x
	Orchisia costata (Meigen, 1826)	x	
	Pygophora respondens (Walker, 1859)		x
	Stomoxys calcitrans (Linnaeus, 1758)	x	
Nannodastidae	Nannodastia sp.		x
Phoridae	Dohriphora cornuta (Bigot, 1857)		x
	Megaselia setaria (Malloch, 1912)		x
	Puliciphora sp.		x
Platystomatidae	Scholastes carolinensis Enderlein, 1924		x
Psychodidae	Psychoda mediocris Quate, 1959		x
Sarcophagidae	Sarcophaga gressitti Hall & Bohart, 1951	x	
	Sarcophaga karnyi (Hardy, 1927)	x	
	Sarcophaga misera (Walker, 1849)	x	
	Sarcophaga peregrina (Robineau-Desvoidy, 1830)		x
Sciaridae	Scythropochroa quadrispinosa Steffan, 1969		x
Sphaeroceridae	Coproica hirtula (Rondani, 1880)		x
	Poecilosomella punctipennis (Wiedemann, 1824)		x
	Gen. sp.		x
Syrphidae	Lathyrophthalmus arvorum (Fabricius, 1787)		x
Tephritidae	Bactrocera ochrosiae (Malloch, 1942)	x	
	Chaetodacus dorsalis, misid.		

Order/Family	**Taxon***	**Prev. Publ.**	**This Study**
DIPTERA (flies, gnats, midges) [continued]			
Tephritidae	Euphranta lemniscata (Enderlein, 1911)	x	
	Spathulina acroleuca Schiner, 1868	x	
Ulidiidae	Notogramma cimiciforme Loew, 1868	x	x
	Gen. sp.		
EMBIIDA (web spinners)			
Oligotomidae	Oligotoma humbertiana (Saussure, 1896)		x
HEMIPTERA (true bugs)			
Anthocoridae	Buchaniella sodalis (White, 1878)	x	
	Lasiochilus marianensis Usinger, 1946	x	
	Lasiochilus swezeyi Usinger, 1946	x	
Coreidae	Leptocorixa acuta (Thunberg, 1783)	x	
	Leptoglossus australis (Fabricius, 1774)	x	
	Leptoglossus membranaceus (Fabricius)		
	Melanacauthus margineguttatus Distant, 1911	x	
Deltocephalidae	Balclutha rufofasciata (Merino, 1936)	x	
Gerridae	Halobates flaviventris Eschscholtz, 1822		x
Hermatobatidae	Hermatobates sp.		x
Lygaeidae	**Bedunia pagana Barber, 1958**	x	
	Cligenes marianensis Usinger, 1946	x	
	Nysius pulchellus Stål, 1859	x	
	Pachybrachius nigriceps (Dallas, 1852)	x	
Mesoveliidae	Mesovelia vittigera Horvath, 1895		x
Miridae	Campylomma breviceps Usinger, 1946	x	
	Campylomma brunneicollis Usinger, 1946	x	
	Campylomma lividicornis Reuter, 1912	x	
	Camplyomma nr. wakeana Schuh, 1984		x
	Creontiades pallidifer (Walker, 1873)	x	
	Eurystylus costalis unicolor Poppius, 1911	x	
	Lygocoris kusaiensis (Carvalho, 1956)	x	
	"Lygus" n. sp.		x
	Taylorilygus pallidulus (Blanchard, 1852)	x	
	Trigonotylus dohertyi (Distant, 1904)	x	
Nabidae	Reduviolus capsiformis (Germar, 1837)	x	x
Plataspidae	Coptosoma xanthogramma (White, 1842)		x
Reduviidae	Physoderes minor Usinger, 1946		x
	Scadra rufidens Stål, 1859		x
Saldidae	Saldula palauana Drake, 1961		x
Veliidae	Halovelia bergrothi Esaki, 1926		x
	Microvelia diluta Distant, 1909		x
HOMOPTERA (sucking bugs, aphids, scale insects)			
Aleyrodidae	Gen. sp.		x
	Neomaskellia bergii (Signoret, 1868)	x	
Aphididae	Aphis gossypii Glover, 1877	x	
	Gen. sp.	x	x
Aradidae	Mezira sp.		x

Order/Family	Taxon*	Prev. Publ.	This Study
Cicadellidae	Acertagallia sp.		x
HOMOPTERA (sucking bugs, aphids, scale insects) [continued]			
Coccidae	Saissetia coffeae (Walker, 1852)	x	
	Saissetia hemisphaericum		
	Saissetia nigra (Nietner, 1861)	x	
	Saissetia oleae (Bernard, 1782)	x	
Diaspididae	Hemiberlesia lataniae (Signoret, 1869)	x	
	Lepidosaphes esakii Takahashi, 1939	x	
Monophlebidae	Icerya aegyptiaca (Douglas, 1890)	x	x
Pentatomidae	Bulbostethus transversalis Ruckes, 1963	x	
	Geotomus pygmaeus (Dallas, 1851)	x	
	Piezodorus hybneri (Gmelin)	x	
Pseudococcidae	Dysmicoccus cocotis (Maskell, 1890)	x	
	Dysmicoccus saipanensis (Siraiwa, 1933)		
	Ferrisia virgata (Cockerell, 1893)	x	
Psyllidae	Trioza guama Caldwell, 1942	x	x
	Trioza propria Tuthill, 1951		
Scutelleridae	Coleotichus breddini Shouteden, 1905	x	x
HYMENOPTERA (wasps, bees, ants)			
Agaonidae	Ceratosolen sp.		x
	Liporrhopalum? sp.		x
	Sycoscapter sp.		x
Aphelinidae	Aneristus ceroplastae Howard, 1895	x	
Apidae	Apis mellifera Linnaeus, 1758	x	x
Bethylidae	Scleroderma sp.		x
Braconidae	Apanteles sp.	x	
	Doryctes sp.	x	
	Phaneratoma sp.		x
Elasmidae	Elasmus sp.		x
Eucharidae	Chalcura upeensis Fullaway, 1913	x	
Eulophidae	Hemiptarsenus varicornis (Girault, 1913)		x
	Tetrastichinae Gen. sp.		x
Eumenidae	Delta esuriens (Fabricius) ssp.	x	
	Gen. sp.	x	
	Rhynchium brunneum (Fabricius, 1793)		x
	Subancisatrocerus sp.	x	
Evaniidae	Evania appendigaster (Linnaeus, 1758)	x	x
Formicidae	Anoplolepis gracilipes (Smith, 1857)	x	x
	Anoplolepis longipes Jerdon, 1851		
	Camponotus chloroticus Emery, 1897	x	x
	Cardiocondyla kagutsuchi Terayama, 1999		x
	Cardiocondyla obscurior Wheeler, 1929		x
	Cardiocondyla tjibodana Karavaiev, 1935		x
	Hypoponera punctatissima (Roger, 1859)	x	
	Iridomyrmex anceps (Roger, 1863)		x
	Monomorium australicum Forel, 1907		x
	Monomorium chinense Santschi, 1925	x	x
	Monomorium destructor (Jerdon, 1851)	x	x
	Monomorium floricola Jerdon, 1851	x	x

Order/Family	**Taxon***	**Prev. Publ.**	**This Study**
HYMENOPTERA (wasps, bees, ants) [continued]			
Formicidae	Monomorium sechellense Emery, 1894	x	
	Monomorium fossulatum Wilson & Taylor, 1967		
	Nylanderia bourbonica (Forel, 1886)	x	x
	Odontomachus simillimus (Smith, 1858)	x	x
	Odontomachus haemotodus (Linnaeus, 1758), misid.		
	Paratrechina longicornis (Latreille, 1802)		x
	Pheidole sp. B	x	
	Pheidole nindi Mann, 1919		x
	Pheidole umbonata Mayr, 1870	x	x
	Platythyrea parallela (Smith, 1859)	x	x
	Strumigenys emmae (Emery, 1890)	x	x
	Quadristruma emmae (Emery, 1890)		
	Tapinoma melanocephalum (Fabricius, 1793)	x	x
	Tapinoma sp.	x	x
	Technomyrmex difficilis Forel, 1892		x
	Tetramorium bicarinatum Nylander, 1846	x	x
	Tetramorium lanuginosum Mayr, 1870	x	x
	Tetramorium simillimum (Smith, 1851)	x	x
	Tetramorium smithi Mayr, 1879		x
	Tetramorium tonganum Mayr, 1870		x
Halictidae	Homalictus vexator (Krombein, 1950)	x	
Ichneumonidae	Echthromorpha agrestoria insidiator (Smith, 1863)		x
Ichneumonidae	Echthromorpha agrestoria conopleura Krieger, 1909	x	
	Echthromorpha conopleura Krieger, 1909		
	Trathala flavoorbitalis (Cameron, 1907)	x	
Megachilidae	**Heriades paganensis Yasumatsu, 1942**	x	
	Eriades sp.		
	Megachile laticeps Smith, 1853	x	
	Megachile fullawayi Cockerell, 1914	x	
Mymaridae	Gen. sp.		x
Pompilidae	Paracyphononyx pedestris (Smith, 1855)		x
Scelionidae	Scelio sp.		x
Sphecidae	Chalybion bengalense (Dahlbom, 1845)	x	x
	Liris aurulenta (Fabricius, 1787)	x	
	Liris opulenta (Le Peletier, 1845)		
	Liris aurata (Fabricius, 1787)	x	x
	Motes manilae (Ashmead, 1905)	x	
	Sceliphron nr. laetum Smith, 1856		x
	Trypoxylon nr. thaianum Tsuneki, 1961	x	x
Trichogrammatidae	Trichogramma sp.		x
Vespidae	Delta esuriens (Fabricius, 1787)		x
	Odynerus paganensis Yasumatsu, 1945	x	
	Odynerus mariannensis Bequaert & Yasumatsu		
	Odynerus haemorrhoidalis quinquecinctus (Fabr.)	x	
	Pachyodynerus nasidens (Latreille, 1832)		x
	Polistes olivaceus (de Geer, 1773)	x	x
	Ropalidia marginata sundaica van der Vecht, 1941	x	

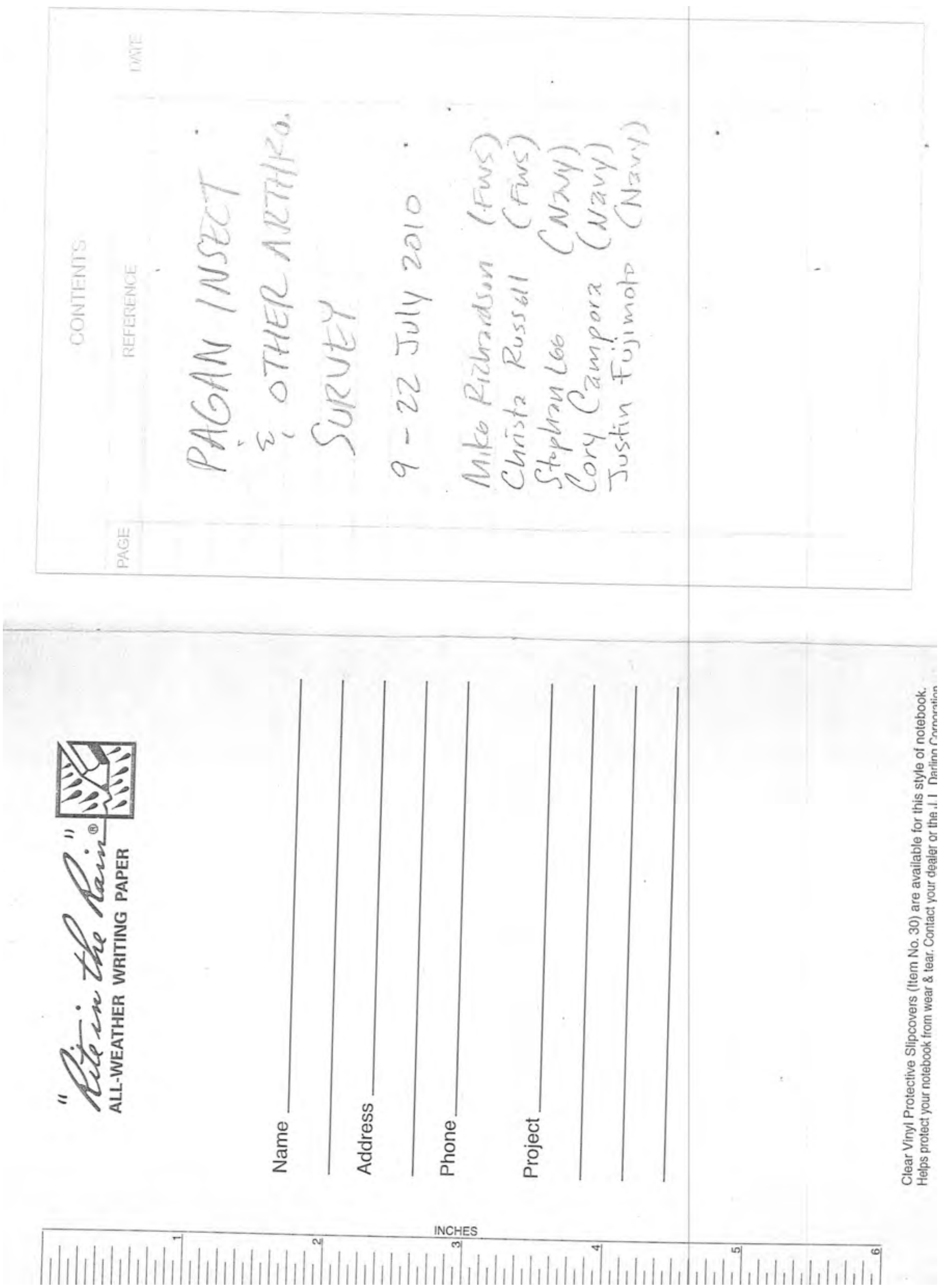
Order/Family	Taxon*	Prev. Publ.	This Study
ISOPODA (sow bugs, pill bugs, wood lice)			
Armadillidae	Gen. sp. 1	x	x
Fam.	Gen. sp. 2	x	
ISOPTERA (termites)			
Rhinotermitidae	Prorhinotermes inopinatus Silvestri		x
LEPIDOPTERA (moths, butterflies)			
Cosmopterygidae	Asymphorodes sp.		x
	Gen. sp.		x
Crambidae	Autocharis sp.		x
Geometridae	Chloroclystis scintillata Prout, 1932		x
	Scopula homodoxa Meyrick, 1886		x
Hesperiidae	Badamia exclamationis (Fabricius, 1775)	x	x
Lycaenidae	Petrelaea dana (de Niceville, 1884)		x
Noctuidae	Achaea serva (Fabricius, 1775)	x	
	Callopistria maillardi (Guenée, 1862)	x	x
	Earias ochrophylla Turner, 1902	x	
	Melanitis leda (Linnaeus, 1758) ssp.	x	x
	Mocis fragalis (Fabricius, 1775)	x	
	Mocis undata (Fabricius, 1775)	x	
Nymphalidae	Euploea eunice (Quoy & Gaimard, 1824)	x	x
	Hypolimas bolina (Linnaeus, 1758)		x
Papilionidae	Papilio polytes Linnaeus, 1758 ssp.	x	x
	Papilio xuthus Linnaeus, 1767	x	
Pterophoridae	Gen. sp.		x
Pyralidae	Cryptolabes sp.		x
	Endotricha sp.		x
	Etiella nr. grisea Hampson, 1903		x
Tineidae	Erecthias sp.		x
MANTODEA (mantids)			
Mantidae	Orthodera burmeisteri Wood-Mason, 1889	x	x
NEUROPTERA (lacewings, ant lions)			
Chrysopidae	Brinckochrysa scelestes (Banks, 1911)		x
	Chrysoperla externa (Haqen, 1861)		x
	Chrysoperla krakatauensis Tsukaguchi, 1988	x	
	Mallada basalis Walker, 1852	x	
	Chrysopa basalis Walker		
	Plesiochrysa oceanica (Walker, 1852)		x
	Chrysopa oceanica Walker		
Hemerobiidae	Gen. sp.		x
Myrmeleontidae	Distoleon bistrigatus (Rambur, 1842)	x	
	Myrmeleon sp.		x
ODONATA (dragonflies, damselflies)			
Agrionidae	Ischnura aurora (Brauer, 1865)	x	x
Libellulidae	Diplacodes bipunctatus (Brauer, 1865)	x	x

Order/Family	Taxon*	Prev. Publ.	This Study
ODONATA (dragonflies, damselflies) [continued]			
Libellulidae	Macrodiplax cora (Brauer, 1867)	x	
	Rhyothemis regia chalcoptilon (Brauer, 1867)	x	x
ORTHOPTERA (crickets, grasshoppers)			
Acrididae	Aiolopus thalassinus dubius Willemse, 1923		x
	Aiolopus thalassinus tamulus (Fabricius, 1781)	x	x
	Cyrtacanthridinae Gen. sp. 1		x
	Cyrtacanthridinae Gen. sp. 2		x
	Cyrtacanthridinae Gen. sp. 3		x
	Locusta migratoria manilensis (Mayen, 1835) *Locusta migratoria*	x	x
	Valanga excavata (Stål, 1861)		x
	Valanga nigricornis nr. ssp. carolinensis		x
Conocephalidae	Euconocephalus nasutus (Thunberg, 1815)	x	
Gryllidae	Gryllodes sigillatus (Walker, 1859)		x
	Gryllus sp.		x
	Teleogryllus oceanicus (Le Guillou, 1841)		x
Myrmecophilidae	Myrmecophilus leei Kistner & Chong, 2007		x
Tetrigidae	Gen. sp. 1		x
	Gen. sp. 2		x
Tettigoniidae	Mecopoda elongata (Linnaeus, 1758)		x
PHASMATODEA (walking sticks)			
Phasmatidae	Acanthograeffea denticulata (Redtenbacher, 1908)	x	
PSEUDOSCORPIONIDA (pseudoscorpions)			
Atemnidae	Oratemnus samoanus		x
Chernetidae	Smeringochernes guamensis Beier, 1957	x	
	Tyrannochthonius chamarro Chamberlin, 1947	x	
Olpiidae	Beierolpium oceanicum (With, 1907)	x	
Undetermined	Gen. sp.		x
PSOCOPTERA (book lice, bark lice)			
Archipsocidae	Archipsocus sp.		x
Caeciliidae	Caecilius analis Banks, 1931	x	
	Caecilius sp. nr. marianus Thornton et al., 1972		x
Ectopsocidae	Ectopsocus sp.		x
Lepidopsocidae	Lepidopsocus sp.		x
Myopsocidae	Phlodotes sp.		x
Peripsocidae	Peripsocus sp.		x
Pseudocaciliidae	Pseudocaecilius sp.		x
Psocidae	Ptycta sp.		x
SCORPIONIDA (scorpions)			
Ischnuridae	Liocheles australasiae (Fabricius, 1775)	x	x
Fam.	Gen. sp.	x	

Order/Family	Taxon*	Prev. Publ.	This Study
SIPHONAPTERA (fleas)			
Pulicidae	Ctenocephalides felis felis (Bouché, 1835)	x	
THYSANOPTERA (thrips)			
Phlaeothripidae	Allothrips megacephala Hood, 1908		x
	Allothrips sp.	x	
	Phlaeothripinae Gen. sp.		x
	Dexiothrips madrasensis (Ananthakrishnan, 1964)	x	
THYSANURA (bristletails, silverfish)			
Fam.	Gen. sp.		x
TOTALS		**188**	**288**
Grand total of species known from Pagan -- 416			

*Taxa listed in **boldface** are endemic species known only from Pagan Island.

APPENDIX III. CORY CAMPORA FIELD NOTES



1.) Pagan, CNMI
Lake Sanhiyon (saltwater lake)
9 July 2010
M. Richardson, C. Russell, S. Lee,
J. Fujimoto, and C. Campora

- Sweep Netting
- Aquatic Dip Netting
- General Collecting

2.) Pagan, CNMI
Rocky Coast from Lake
Sanhiyon south to Bandeera
Peninsula
9 July 2010
M. Richardson and S. Lee

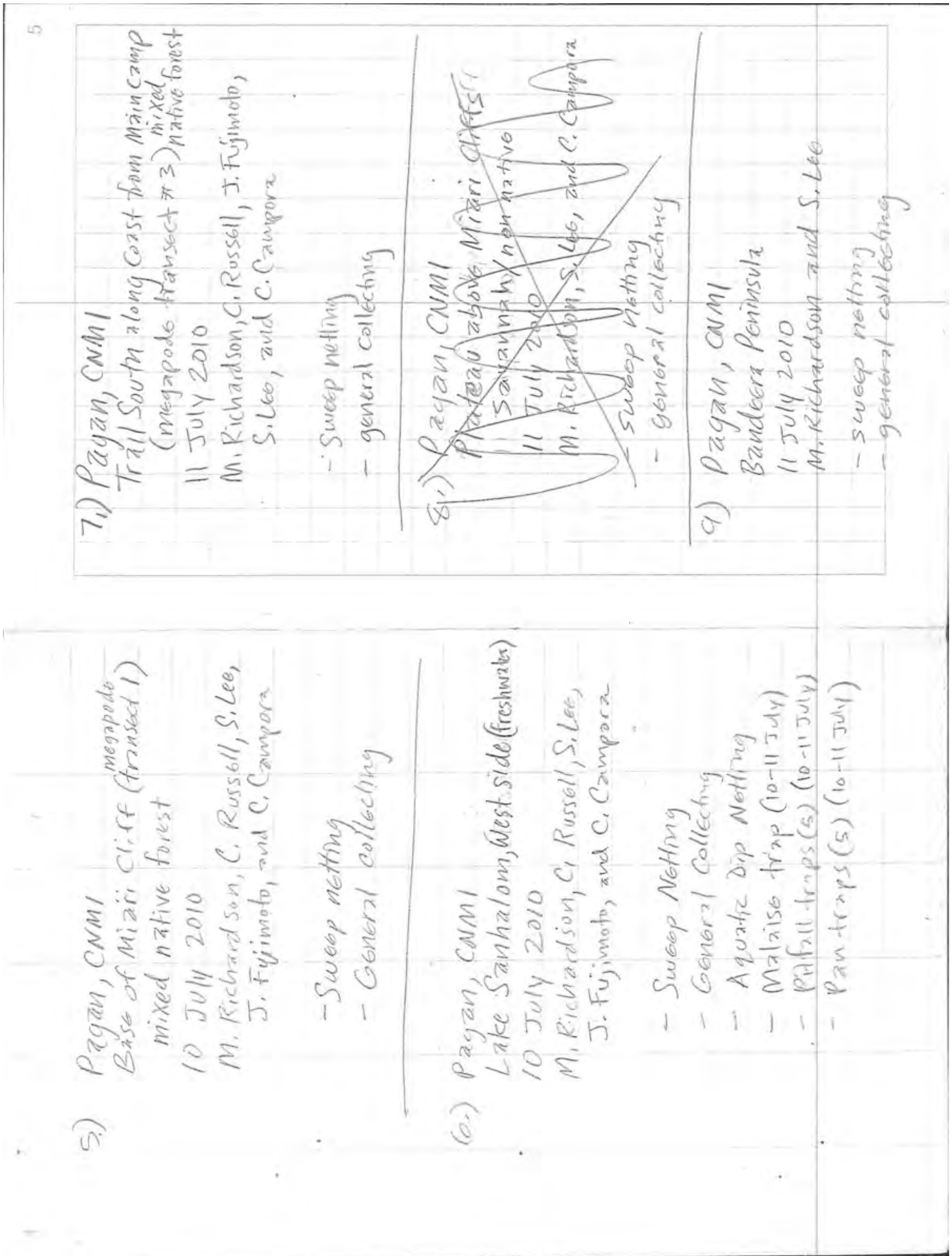
- Sweep Netting
- General Collecting
- Collecting from rocky pools

3.) Pagan, CNMI
Ironwood forest south of
lake Sanhiyon (swordfern
understory)
9 July 2010
C. Campora, J. Fujimoto, and
C. Russell

- sweep netting
- general collecting

4.) Pagan, CNMI
Main Camp near runway –
mixed / grassy field / ironwood
9 July 2010
M. Richardson, C. Russell, S. Lee,
J. Fujimoto, and C. Campora

- Malaise trap (9–10 July)
- Pitfall traps (5) (9–10 July)
- Blacklight (night of 9 July)



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5.) Pagan, CNMI
Base of Miari Cliff (megapode transect 1)
mixed native forest
10 July 2010
M. Richardson, C. Russell, S. Lee,
J. Fujimoto, and C. Campora

- Sweep netting
- General collecting

6.) Pagan, CNMI
Lake Sanhalom, West side (freshwater)
10 July 2010
M. Richardson, C. Russell, S. Lee,
J. Fujimoto, and C. Campora

- Sweep Netting
- General Collecting
- Aquatic Dip Netting
- Malaise trap (10–11 July)
- Pitfall traps (5) (10–11 July)
- Pan traps (5) (10–11 July)

7.) Pagan, CNMI
Trail South along Coast from Main Camp
(megapode transect #3) mixed native forest
11 July 2010
M. Richardson, C. Russell, J. Fujimoto,
S. Lee, and C. Campora

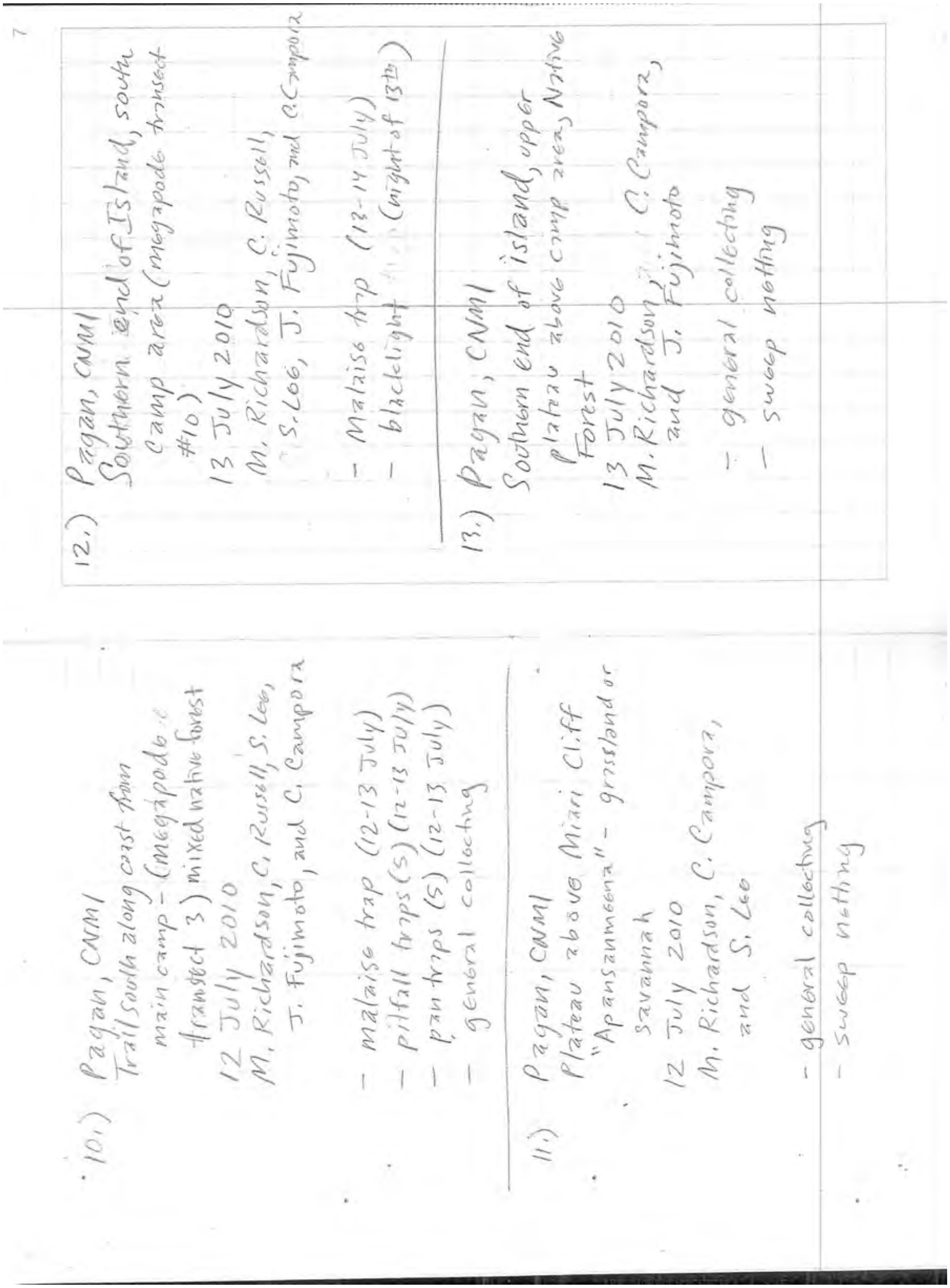
- Sweep netting
- general collecting

8.) Pagan, CNMI
Plateau above Miari Cliffs
Savannah / non native
11 July 2010
M. Richardson, S. Lee, and C. Campora

- Sweep netting
- general collecting

9.) Pagan, CNMI
Bandeera Peninsula
11 July 2010
M. Richardson and S. Lee

- sweep netting
- general collecting



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10.) Pagan, CNMI
Trail south along coast from main camp – (megapode transect 3) mixed native forest
12 July 2010
M. Richardson, C. Russell, S. Leo, J. Fujimoto, and C. Campora

- malaise trap (12-13 July)
- pitfall traps (5) (12-13 July)
- pan traps (5) (12-13 July)
- general collecting

11.) Pagan, CNMI
Plateau above Miari Cliff "Apansanmeena" – grassland or savannah
12 July 2010
M. Richardson, C. Campora, and S. Leo

- general collecting
- sweep netting

12.) Pagan, CNMI
Southern end of Island, south camp area (megapode transect #10)
13 July 2010
M. Richardson, C. Russell, S. Leo, J. Fujimoto, and C. Campora

- Malaise trap (13-14 July)
- blacklight (night of 13th)

13.) Pagan, CNMI
Southern end of island, upper plateau above camp area, Native Forest
13 July 2010
M. Richardson, C. Campora, and J. Fujimoto

- general collecting
- sweep netting

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14.) Pagan, CNMI
Southern end of island, upper plateau, mixed native forest at base of cliff (megapode transect #11)
14 July 2010
C. Campora, J. Fujimoto, and C. Russell

- general collecting
- sweep netting

15.) Pagan, CNMI
Southern end of island, South volcano, forest inside caldera
14 July 2010
M. Richardson

- general collecting
- sweep netting

16) Pagan, CNMI
Bandeera Peninsula - coastal
15 July 2010
M. Richardson, C. Russell, J. Fujimoto, S. Lee, and C. Campora

- malaise trap (15-16 July)
- pan traps (5) (15-16 July)
- pitfall traps (5) (15-16 July)
- blacklight (night of 15 July)

17.) Pagan, CNMI
Ironwood forest bordering airfield
16 July 2010
C. Campora

- sweep netting

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18.) Pagan, CNMI
Lower main camp, near
base of Miari cliff
16 July 2010
C. Campora

- blacklight

19.) Pagan, CNMI
Southern end of island, South
Volcano, inside caldera
16 July 2010
M. Richardson, S. Lee, and
J. Fujimoto

- malaise trap (16-17 July)
- blacklight (night of 16 July)
- general collecting
- sweep netting
- pitfall traps (5) (16-17 July)
- pan traps (5) (16-17 July)

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