TECHNICAL REPORT

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MARINE MAMMAL STRANDINGS ASSOCIATED WITH U.S. NAVY SONAR ACTIVITIES

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1 INTRODUCTION

Although this report provides general information on threats to marine mammals (natural and human-related) that may cause or contribute to strandings, the purpose of this report is to present specific information regarding marine mammal stranding events that may have been associated with U.S. Navy sonar activities. Five stranding events that have been linked to sonar (see Section 3, Stranding Events Associated with U.S. Navy Sonar Activities) and six strandings thought to be linked to sonar but later determined that no such link exists (see Section 4, Strandings Speculated but not Linked to U.S. Navy Sonar Activities) are discussed in detail.

1.1 What is a Stranded Marine Mammal?

When an alive or dead marine mammal swims or floats onto shore and becomes “beached” or incapable of returning to sea, the event is termed a “stranding” (Geraci et al., 1999; Geraci & Lounsbury, 2005; Perrin & Geraci, 2002). Animals outside of their “normal” habitat are also sometimes considered “stranded” even though they may not have beached themselves [e.g., the July 2004 Hanalei Bay “mass stranding event” (Southall et al., 2006)]. The United States’ legal definition of a stranding is “(A) a marine mammal is dead and is (i) on a beach or shore of the United States or (ii) in waters under the jurisdiction of the United States (including any navigable waters); or (B) a marine mammal is alive and is (i) on a beach or shore of the United States and is unable to return to the water; (ii) on a beach or shore of the United States and, although able to return to the water, is in need of apparent medical attention; or (iii) in the waters under the jurisdiction of the United States (including any navigable waters), but is unable to return to its natural habitat under its own power or without assistance” (16 United States Code [U.S.C.] section 1421h).

The majority of animals that strand are found dead or dying. For animals that strand alive, human intervention through medical aid or guidance seaward may be required for the animal to return to the sea. If unable to return to sea, rehabilitation at an appropriate facility may be determined as the best opportunity for animal survival. Along the coasts of the continental U.S., Alaska, and the U.S. Pacific Islands (including Hawaii) over a 9-year period (2001–2009), there were a total of 51,649 reported marine mammal strandings (12,545 cetaceans [average 1,394 per year] and 39,104 pinnipeds [average 4,345 per year]) (NMFS, 2016a).

Strandings are generally categorized as single, mass, or unusual mortality events. The most frequent type of stranding involves only one animal (or a mother/calf pair). Mass stranding involves two or more marine mammals of the same species other than a mother/calf pair (Wilkinson, 1991), and may span one or more days and range over several miles (Bradshaw et al., 2006; Freitas, 2004; Simmonds & Lopez-Jurado, 1991; Walsh et al., 2001). Several hypotheses have been given for mass strandings or out of habitat aggregations, which include the impact of shallow beach slopes on odontocete echolocation, disease or parasites, severe weather or tidal events, geomagnetic anomalies that affect navigation, following a food source in close to shore, avoiding predators, social interactions that cause some cetaceans to come to the aid of stranded conspecifics, and human interactions of various kinds (e.g., fisheries interactions) (Geraci & Lounsbury, 2005). Generally, inshore species do not strand in large numbers but as individuals. By contrast, pelagic species strand more often in larger numbers.

In North America, only a few species typically strand in groups of 15 or more, such as sperm whales, pilot whales, false killer whales, Atlantic white-sided dolphins, white-beaked dolphins, and rough-toothed dolphins (Odell, 1987; Walsh et al., 2001). In addition to these, some species, such as pilot whales, false-killer whales, and melon-headed whales, occasionally strand in groups of 50 to 150 or more (Aragones et al., 2010; Geraci et al., 1999; Southall et al., 2006). All of these normally pelagic species are highly sociable and infrequently encountered in shallow coastal waters. Species that commonly strand in small numbers include pygmy killer whales, common dolphins, bottlenose dolphins, Pacific white-sided dolphins, Frasier's dolphins, gray whale and humpback whale, harbor porpoise, Cuvier's beaked whales, California sea lions, and harbor seals (Geraci & Lounsbury, 2005; Mazzuca et al., 1999).

Unusual mortality events can be a series of single strandings or mass strandings, or unexpected mortalities (i.e., die-offs) that occur under unusual circumstances (Dierauf & Gulland, 2001; Gulland, 2006; Harwood, 2002). As published by the National Marine Fisheries Service (NMFS) (National Marine Fisheries Service, 2006), revised criteria for defining an unusual mortality event include:

(1) A marked increase in the magnitude or a marked change in the nature of morbidity (incidence of disease), mortality, or strandings when compared with prior records.
(2) A temporal change in morbidity, mortality, or strandings is occurring.
(3) A spatial change in morbidity, mortality, or strandings is occurring.
(4) The species, age, or sex composition of the affected animals is different than that of animals that are normally affected.
(5) Affected animals exhibit similar or unusual pathologic findings, behavior patterns, clinical signs, or general physical condition (e.g., blubber thickness).
(6) Potentially significant morbidity, mortality, or stranding is observed in species, stocks or populations that are particularly vulnerable (e.g., listed as depleted; threatened or endangered; or declining). For example, stranding of three or four right whales may be cause for great concern whereas stranding of a similar number of fin whales may not.
(7) Morbidity is observed concurrent with or as part of an unexplained continual decline of a marine mammal population, stock, or species.

Unusual mortality events are usually unexpected and infrequent. As discussed below, unusual environmental conditions are probably responsible for most unusual mortality events and marine mammal die-offs (Geraci et al., 1999; Vidal & Gallo-Reynoso, 1996; Walsh et al., 2001). From 1991 through April 2017, there have been 63 formally recognized unusual mortality events in the United States. The unusual mortality events either involved single or multiple species and dozens to hundreds of individual marine mammals per event (NMFS, 2016b). Causes have been determined for 32 of the 62 unusual mortality events, including infections, biotoxins, human interactions, and malnutrition.

1.2 United States Stranding Response Organization

In 1992, Congress amended the Marine Mammal Protection Act to establish the Marine Mammal Health and Stranding Response Program under authority of NMFS. The Marine Mammal Health and Stranding Response Program was created out of concern over marine mammal mortalities, to formalize the stranding response process, to focus efforts being initiated by numerous local stranding organizations, and as a result of public concern.

Major elements of the Marine Mammal Health and Stranding Response Program include:

- National Marine Mammal Stranding Network
- Marine Mammal Unusual Mortality Event Program
- National Marine Mammal Tissue Bank and Quality Assurance Program
- Marine Mammal Health Biomonitoring, Research, and Development
- Marine Mammal Disentanglement Network
- John H. Prescott Marine Mammal Rescue Assistance Grant Program
- Information Management and Dissemination

The United States has a well-organized network in coastal states to respond to marine mammal strandings. Overseen by NMFS, the National Marine Mammal Stranding Network is comprised of smaller organizations manned by professionals and volunteers from nonprofit organizations, aquaria, universities, and state and local governments trained in stranding response protocols, animal health, and disease investigation. Through a national coordinator and six regional coordinators, NMFS authorizes and oversees stranding response activities and provides specialized training for network participants.

Historically, stranding reporting and response efforts have been inconsistent, although they have improved considerably within the United States over the last 25 years. Because of this, the current ability to interpret long-term trends in marine mammal stranding is limited. Nevertheless, stranding events provide scientists and resource managers information not available via other means, and may be the only way to learn key biological information about certain species, such as their distribution, seasonal occurrence, and health (Danil et al., 2010; Geraci & Lounsbury, 2005; Walsh et al., 2001). In addition, necropsies, which are performed on stranded animals when the situation and resources allow, often supply the most effective means of investigating the causation of a stranding event.

2 POTENTIAL FACTORS INFLUENCING AND CAUSES FOR MARINE MAMMAL STRANDING

Like any wildlife population, there are natural mortality events that influence marine mammal population dynamics, including starvation, predation, aging, reproductive success, and disease (Carretta et al., 2007; Geraci et al., 1999). Strandings may be reflective of this natural cycle or caused by anthropogenic sources (i.e., human impacts) (Carretta et al., 2016; Cassoff et al., 2011; McGeady et al., 2016). Fossil records indicate mass strandings of marine mammals occurring in the Miocene epoch millions of years prior to human presence (Pyenson et al., 2014), and there are also reports of marine mammal strandings tracing back to ancient Greece (Aristotle). Current science suggests that multiple factors, both natural and man-made, may act alone or in combination to cause a marine mammal to strand (Culik, 2004; Geraci et al., 1999; Geraci & Lounsbury, 2005; National Research Council, 2006; Perrin & Geraci, 2002). While post-stranding data collection and necropsies of dead animals are attempted in an effort to find a possible cause for the stranding, it is often difficult to pinpoint one factor as a definitive cause of a given stranding (e.g., Bachman et al., 2015; Hansen et al., 2016; Vianna et al., 2016). An animal weakened from one ailment potentially becomes susceptible to various other stressors (e.g., secondary infections), making it difficult to determine the initial factor in a possible cascade of events. In many stranding cases, scientists never learn the exact reason for the stranding.

Contributing factors and direct causes for marine mammal strandings may be both natural and anthropogenic (each of which will be discussed in detail below):

- Natural Contributing Factors and Causes
    - Disease
    - Natural neurotoxins
    - Hearing deficit
    - Weather and climatic influences
    - Navigation error
    - Social cohesion
    - Predation
- Anthropogenic Contributing Factors and Causes

  - Fisheries interaction
  - Direct trauma
  - Marine mammal viewing
  - Ingestion of marine debris
  - Toxic pollution
  - Acute noise exposure

2.1 Natural Contributing Factors and Causes of Stranding

Significant natural causes of mortality, die-offs, and stranding include disease and parasitism; marine neurotoxins from algae; navigation errors that lead to inadvertent stranding; and population and climatic influences that impact the distribution and abundance of marine mammals and potential food resources (i.e., starvation). Other natural mortality not discussed in detail includes predation by other species such as sharks (Cockcroft et al., 1989; Heithaus, 2001), killer whales (Constantine et al., 1998; Guinet et al., 2000; Pitman et al., 2001), and some species of pinniped (Hiruki et al., 1999; Robinson et al., 1999).

2.1.1 Disease

Like other mammals, marine mammals frequently suffer from a variety of diseases of viral, bacterial, parasitic, and fungal origin (Danil et al., 2014; Dunn et al., 2001; Harwood, 2002; Visser et al., 1991). Gulland and Hall (2005) provide a more detailed summary of individual and population effects of marine mammal diseases.

Microparasites such as bacteria, viruses, and other microorganisms (typically not visible to the naked eye) are commonly found in marine mammal habitats and usually pose little threat to a healthy animal (Geraci et al., 1999). Since the 1980s, however, it has been realized that viral infections may be associated with marine mammal die-offs (Domingo et al., 1992; Geraci & Lounsbury, 2005). In large populations, studies have shown that cetacean morbillivirus is widespread but the animals develop an immunity due to frequent exposure. However, if a population is unexposed for a number of years, such as fragmented populations of coastal dolphins, an outbreak can occur (Geraci & Lounsbury, 2005). Morbillivirus suppresses a host’s immune system, increasing risk of secondary infection (Harwood, 2002). A mass die-off of bottlenose dolphins in the Atlantic that occurred from 1987−1988 was later associated with the presence of morbillivirus in over 50% of the dolphins investigated (Lipscomb et al., 1994). A bottlenose dolphin unusual mortality event in 1993 and 1994 was also likely caused by morbillivirus; die-offs ranged from northwestern Florida to Texas, with an increased number of deaths as it spread (National Marine Fisheries Service, 2008). Similarly, a 2004 unusual mortality event in Florida was associated with morbillivirus (National Marine Fisheries Service, 2004), and from 2013 to 2015, morbillivirus was believed to have caused another bottlenose dolphin unusual mortality event along the Atlantic coast from Florida through New York (NMFS, 2016c). During this same time period, another species of cetacean, tropical bottlenose whale (*Indopacetus pacificus*), that stranded in New Caledonia also presented with morbillivirus (Garrigue et al., 2016). Stranded marine mammals with morbillivirus have been reported in increasing numbers and in varying areas across the globe including the tropical Pacific and the Mediterranean (Jacob et al., 2016; Mazzariol et al., 2015; Mazzariol et al., 2017; West et al., 2012; West et al., 2015).

Morbillivirus is not, however, the only infectious virus associated with strandings. Influenza A was responsible for the first reported mass mortality in the United States, occurring along the coast of New England in 1979–1980 (Harwood, 2002). Canine distemper virus (a type of morbillivirus) has been responsible for large scale pinniped mortality events and die-offs (Grachev et al., 1989; Gulland & Hall, 2005; Kennedy et al., 2000), while a bacteria, *Leptospira pomona*, is responsible for periodic die-offs in California sea lions about every 4 years (Gulland et al., 1996; Gulland & Hall, 2005). It is difficult to determine whether microparasites commonly act as a primary pathogen, or whether they show up as a secondary infection in an already weakened animal (Geraci et al., 1999). Most marine mammal die-offs from infectious disease in the last 35 years, however, have had viruses associated with them (Geraci et al., 1999; Harwood, 2002; Simmonds & Mayer, 1997).

Some microparasites occurring in marine mammals have been found to transmit through the environment from terrestrial hosts such as *Toxoplasma gondii* from felids, *Sarcocystis cruzi* and *Neospora caninum* from canids, and *S. neurona* from opossums (Barbieri et al., 2016). These infections have been detected in Hawaiian monk seals in recent years. Despite necropsy and examination occurring on carcasses since the 1980s, Toxoplasmosis was first detected in a Hawaiian monk seal in 2004.

Macroparasites are large parasitic organisms (typically visible to the naked eye) that include lungworms, trematodes (parasitic flatworms), nematodes (parasitic roundworms), and protozoans (Diaz-Delgado et al., 2016; Geraci & St. Aubin, 1987; Geraci et al., 1999). Marine mammals can carry many different types of macroparasites and have shown a robust tolerance for sizeable infestations unless compromised by illness, injury, or starvation (Dailey & Vogelbein, 1991; Geraci et al., 1999; Morimitsu et al., 1987). Arteritis and renal disease due to infestation of crassicaudiasis (a type of nematode) has been found in high proportions of stranded Cuvier's beaked whales in the Canarian Archipelago, and is thought to be a leading cause of mortality in this region (Diaz-Delgado et al., 2016). Nasitrema, a usually benign trematode found in the head sinuses of cetaceans (Geraci et al., 1999), can cause damage if it migrates to the brain (Ridgway & Dailey, 1972). As a result, this worm is one of the few directly linked to stranding in cetaceans (Dailey & Walker, 1978; Geraci et al., 1999).

Non-infectious disease, such as congenital bone pathology of the vertebral column (osteomyelitis, spondylosis deformans, and ankylosing spondylitis), has been described in several species of cetacean (Alexander et al., 1989; Kompanje, 1995; Paterson, 1984; Sweeney et al., 2005). In humans, bone pathology, such as ankylosing spondylitis, can impair mobility and increase vulnerability to further spinal trauma (Resnick & Niwayama, 2002). Bone pathology has been found in cases of single strandings (Kompanje, 1995; Paterson, 1984) and in cetaceans prone to mass stranding (Sweeney et al., 2005), possibly acting as a contributing or causal influence in both types of events.

2.1.2 Natural Neurotoxins

Some single cell marine algae common in coastal waters (e.g., dinoflagellates and diatoms) produce toxic compounds that can accumulate (termed bioaccumulation) in the tissues of fish and invertebrates (Gaydos, 2006; Geraci et al., 1999; Harwood, 2002). Marine mammals become exposed to these compounds when they eat contaminated prey, although exposure can also occur through inhalation and skin contact (Van Dolah, 2005). Other algal toxins associated with marine mammal strandings include saxitoxins and ciguatoxins and are summarized by Van Dolah (2005).

The number of unusual mortality events in which the cause has been determined to be associated with biotoxins has increased since 1996 (NMFS, 2016b). In the Gulf of Mexico and along the mid- to southern Atlantic states, "red tides," a form of harmful algal bloom, are created by a dinoflagellate (*Karenia brevis*) (Van Dolah et al., 2003). *Karenia brevis* produces a neurotoxin known as brevetoxin. Brevetoxin has been associated with several marine mammal unusual mortality events within this area (Fire et al., 2010; Fire et al., 2011; Gaydos, 2006; Geraci et al., 1989; Van Dolah et al., 2003; Van Dolah, 2005). On the U.S. West Coast and in the northeast Atlantic, several species of diatoms produce a biotoxin called domoic acid which has been linked to cetacean and sea lion strandings and is a concern for expansion into arctic and subarctic waters (Bargu et al., 2010; Geraci et al., 1999; Goldstein et al., 2008; Greig et al., 2005; Lefebvre et al., 2016; Torres de la Riva et al., 2009; Van Dolah et al., 2003; Van Dolah, 2005). In addition, the highly toxic species *P. australis* bloomed along the North American west coast in the spring of 2015 resulting in the largest geographic extent of domoic acid detection in stranded marine mammals (McCabe et al., 2016).

2.1.3 Hearing Deficits

Odontocetes (toothed whales) use echolocation for navigation and foraging, and hearing deficits could be a factor in stranding events involving odontocetes (Mann et al., 2010; Schlundt et al., 2011). Hearing loss can occur as a result of age, exposure to toxins, and exposure to noise. Age-related hearing loss has been documented in bottlenose dolphins (Houser & Finneran, 2006) and likely occurs in other species (Kloepper et al., 2010). Noise-induced hearing loss in mammals can result from proximity to intense sound or long term exposure to chronic noise; however, susceptibility to temporary and permanent noise-induced hearing loss may vary considerably across species (Finneran et al., 2002; Lucke et al., 2009; Yamato et al., 2016). The potential role of noise-induced hearing loss in stranding events remains unknown.

2.1.4 Weather Events and Climate Influences

Severe storms, hurricanes, typhoons, prolonged temperature extremes, and seasonal oceanographic conditions (e.g., seasonal variation in frontal systems and ocean currents) may lead to localized marine mammal strandings (Bengtson Nash et al., 2017; Geraci et al., 1999; Walker et al., 2005; Walsh et al., 2001). Hurricanes may have been responsible for mass strandings of pygmy killer whales in the British Virgin Islands and Gervais' beaked whales in North Carolina (Mignucci-Giannoni et al., 2000; Norman & Mead, 2001). Storms in 1982–1983 along the California coast led to the death of 2,000 northern elephant seal pups (Le Boeuf & Reiter, 1991). Ice movement along southern Newfoundland has forced groups of blue whales and white-beaked dolphins ashore (Sergeant, 1982). Berini et al. (2015) has used buoy and weather data prior to strandings to create a model of pygmy sperm whale strandings, indicating that more strandings occurred during periods of sustained high wind speeds, low barometric pressures, and swell waves in the week before stranding. McGeady et al. (2016) found significant correlations between environmental variables and stranding rates of deep diving odontocetes, suggesting natural factors such as sea surface temperature, wave height, wave period, and wind direction may increase the likelihood of a stranding event.

The effect of large scale climatic changes to the world's oceans and how these changes impact marine mammals and influence strandings is difficult to quantify given the broad spatial and temporal scales involved and the cryptic movement patterns of many marine mammals (Berini et al., 2015; Learmonth et al., 2006). The most immediate effect is decreased prey availability or altered distributions of prey as a result of changing oceanographic conditions. These may result in increased search effort required by marine mammals (Bargu et al., 2010; Crocker et al., 2006; Elorriaga-Verplancken et al., 2016), potential starvation if not successful, and corresponding stranding due either directly to starvation or to disease or predation while in a more weakened and stressed state (Learmonth et al., 2006; Moore, 2005; Selzer & Payne, 1988; Weise et al., 2006). For example, during El Niño conditions the prey of California sea lions and Guadalupe fur seals have been shown to shift in distribution and abundance, increasing the required effort for foraging (Bargu et al., 2010; Elorriaga-Verplancken et al., 2016; McClatchie et al., 2016). Sea lions have a diverse diet and respond to limited prey availability by switching to less nutritious species. The less nutritious diet combined with the longer foraging trips taken by the adult females has resulted in cycles of malnourished pups correlating with the cyclic El Niño conditions.

Atypical prey distributions may also contribute to stranding by bringing animals closer to shore. For example, in southern Australia, movement of nutrient-rich waters pushed closer to shore by periodic meridional winds (occurring about every 12 to 14 years) may be responsible for bringing marine mammals closer to land, thus increasing the probability of stranding (Bradshaw et al., 2006). Bengston Nash et al. (2017) found a strong correlative relationship between seasonal climatic events (deposition of aeolian dust into the Southern Ocean during the austral summer) and cetacean mass strandings along the Tasmanian coast of Australia. Danil et al. (2010) concluded that strandings of common dolphin species peaked twice (early- to mid-1970s and late-1990s to 2008) coincident with “cool oceanographic regimes” in a coastal area. The authors also suggested that strandings of harbor porpoises in Southern California outside their normal range and temporal changes in stranding rates of Dall’s porpoises and short-finned pilot whales may have been associated with changes in oceanographic conditions. Although the response of animals to altered prey distributions cannot be directly linked to these events, the concept that changing oceanographic conditions influence stranding probabilities provides an overarching model within which to explore possible causations.

2.1.5 Navigation Error

It has been hypothesized that marine mammals may be able to orient to the earth’s magnetic field as a navigational cue and that areas of local magnetic anomalies may influence strandings (Bauer et al., 1985; Kirschvink et al., 1986; Kirschvink, 1990; Klinowska, 1985, 1986; Walker et al., 1992). In a plot of live stranding positions in Great Britain with magnetic field maps, Klinowska (1985, 1986) observed an association between live stranding positions and magnetic field levels. In all cases, live strandings occurred at locations where magnetic minima, or lows in the magnetic fields, intersect the coastline. Kirschvink et al. (1986) plotted stranding locations on a map of magnetic data for the east coast of the United States and noted correlations between stranding sites and locations where magnetic minima intersected the coast. The authors concluded that there were highly significant tendencies for cetaceans to beach themselves near these magnetic minima and coastal intersections. The results supported the hypothesis that cetaceans may have a magnetic sensory system similar to other migratory animals and that marine magnetic topography and patterns may influence long-distance movements (Kirschvink et al., 1986). Walker et al. (1992) examined fin whale swim patterns off the northeastern United States continental shelf and reported that migrating animals aligned with lows in the geometric gradient or intensity. While a similar pattern between magnetic features and marine mammal strandings at New Zealand stranding sites was not seen (Brabyn & Frew, 1994), mass strandings in Hawaii typically were found to occur within a narrow range of magnetic anomalies (Mazzuca et al., 1999).

Some researchers believe stranding may result from reductions in the effectiveness of echolocation within shallow water, especially with the pelagic species of odontocetes that may be less familiar with the coastline (Chambers & James, 2005; Dudok van Heel, 1966; Sundaram et al., 2006). For an odontocete, echoes from echolocation signals contain important information on the location and identity of underwater objects and the shoreline. The authors postulate that the gradual slope of a beach may present difficulties to the navigational systems of some cetaceans, since it is common for live strandings to occur along beaches with shallow, sandy gradients (Brabyn & McLean, 1992; Chambers & James, 2005; Maldini et al., 2005; Mazzuca et al., 1999; Walker et al., 2005). A contributing factor to echolocation interference in turbulent, shallow water is the presence of microbubbles from the interaction of wind, breaking waves, and currents (Chambers & James, 2005). Additionally, ocean water near the shoreline can have increased turbidity (e.g., floating sand or silt, particulate plant matter, etc.) due to the run-off of fresh water into the ocean, either from rainfall or from freshwater outflows (e.g., rivers and creeks). Sundaram et al. (2006) found that certain coastlines known for cetacean strandings have these features that create the described acoustic dead zones. Collectively, these factors can reduce and scatter the sound energy within echolocation signals and reduce the perceptibility of returning echoes. In addition, echolocating animals with hearing deficits (see above) could be at a disadvantage in navigating shallow waters if hearing deficits are sufficient to compromise the reception of echoes from targets ensonified with echolocation signals.

2.1.6 Social Cohesion

Many pelagic species such as sperm whales, pilot whales, melon-headed whales, false killer whales, and some dolphins occur in large groups with strong social bonds between individuals. When one or more animals strand due to any number of causative events, then the entire pod may follow suit out of social cohesion (Conner, 2000; Geraci et al., 1999; Perrin & Geraci, 2002). Social cohesion may be due to intricate social structure as observed with a mass stranding of false killer whales in 1977. The whales became agitated when rescuers moved them to deeper water and separated them from the large male injured in the shallow water; the group remained in the shallows in a tight aggregation until 3 days later when the male died (Conner, 2000). In open water, living as a group provides certain benefits, such as protection and foraging (Conner, 2000). The benefits of living as a group in open water diminish as the group becomes smaller and for lone animals, so once a critical number of animals begins to strand the rest of the pod is likely to strand as well to protect themselves from the dangers of being exposed in the open water (Geraci & Lounsbury, 2005).

2.2 Anthropogenic Contributing Factors and Causes of Stranding

Not including deaths due to historic whaling or whaling that is still conducted in a few nations, there has been an increase in marine mammal mortality events associated with a variety of human activities over the past few decades (Carretta et al., 2016; Culik, 2004; Geraci et al., 1999; Helker et al., 2015; National Marine Fisheries Service, 2012; Vianna et al., 2016). These include fisheries interactions (entanglement, bycatch and directed catch [i.e., the targeted collection of a particular species]), habitat modification (degradation, prey reduction), pollution (marine debris, toxic compounds), direct trauma (vessel strikes, gunshots), and acute noise exposure. Over a 5-year period (2010–2014) along the U.S. West Coast, where there is a larger proportion of human-related strandings, there were 1,480 reported marine mammal human-related injuries and 661 human-related deaths (Carretta et al., 2016). Other human-related factors (e.g., climate change) have the potential to threaten marine mammals to an unknown degree. However, some activities that may be potential threats to marine mammals are still unknown due to insufficient data. Figure 2-1 shows potential worldwide risk to small cetaceans by source. (Note* - the "unknown" in Figure 2-1 does not relate to unknown threats, but rather to a small percentage of species for which too little is known to quantify potential threats.) Similar threats exist for large cetaceans, discussed in more detail in the following sections.

2.2.1 Fisheries Interaction: Bycatch and Entanglement

The incidental catch of marine mammals in commercial fishery activities is a significant threat to the survival and recovery of many populations of marine mammals (Bradford & Forney, 2016)(Bradford & Forney, 2014, 2016; Campagna et al., 2007; Carretta et al., 2016; Carretta et al., 2017; Culik, 2004; Geraci et al., 1999; Geraci & Lounsbury, 2005; Read et al., 2006; Zeeberg et al., 2006).

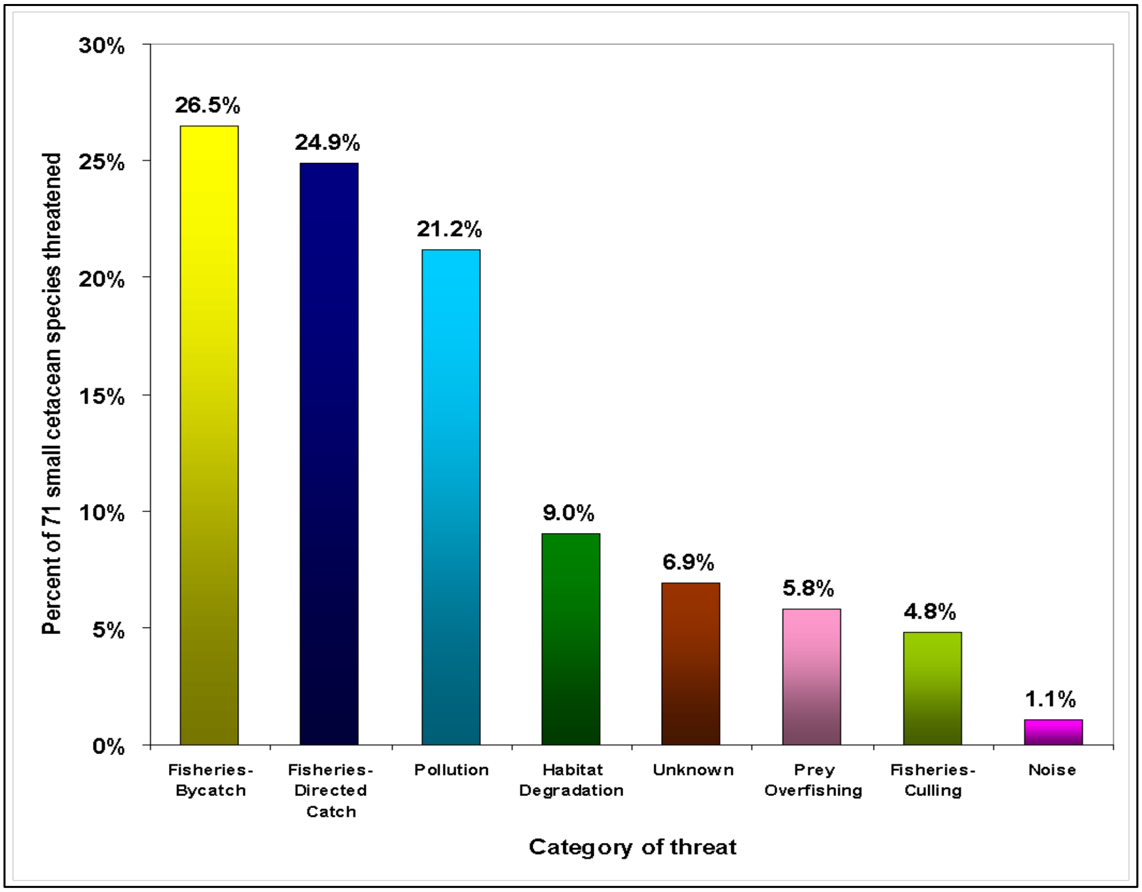

Figure 2-1: Human Threats to Worldwide Small Cetacean Populations

Derived from: (Culik (2004))

Bycatch is the catching of non-target species within a given fishing operation and can include invertebrates, fish, sea turtles, birds, and marine mammals (Carretta et al., 2017; National Research Council, 2006). Read et al. (2006) attempted to estimate the magnitude of marine mammal bycatch in United States and global fisheries. Data on marine mammal bycatch within the United States was obtained from fisheries observer programs, reports of entangled stranded animals, and fishery logbooks, which was then extrapolated to estimate global bycatch by using the ratio of U.S. fishing vessels to the total number of vessels within the world's fleet (Read et al., 2006). Within U.S. fisheries between 1990 and 1999, the mean annual bycatch of marine mammals was 6,215 animals, with a standard error of +/- 448 (Read et al., 2006). Eighty-four percent of cetacean bycatch occurred in gill-net fisheries, with dolphins and porpoises constituting most of the bycatch. There was a 40 percent decline in marine mammal bycatch when comparing bycatch from 1995–1999 to that from 1990–1994. Read et al. (2006) suggest this decline is primarily due to effective conservation measures implemented during this period. Read et al. (2006) then extrapolated bycatch data for the same time period to estimate an annual global bycatch of 653,365 marine mammals, with most of the world's bycatch occurring in gill-net fisheries. In order to provide more accuracy, new models and additional data are being utilized and investigated when estimating bycatch for specific areas or species, or over long periods of time (Carretta et al., 2017; Peltier et al., 2016). With global marine mammal bycatch likely to be in the hundreds of thousands every year, bycatch in fisheries is the single greatest threat to many marine mammal populations around the world.

Entanglement in active or ghost fishing gear is a major cause of death or severe injury among whales. Entangled marine mammals may die as a result of drowning, escape with pieces of gear still attached to their bodies, manage to be set free of their own accord, or are set free by human intervention. Many large whales carry off gear after becoming entangled (Geraci et al., 1999; Read et al., 2006). Often times when a marine mammal swims off with gear attached, the end result is fatal. The gear may encumber the animal's swimming or diving or it can wrap around a crucial body part and tighten over time, causing tissue trauma, affecting circulation, and possibly leading to infection. In addition, the increased drag associated with carrying fishing gear could increase the energy required to swim or dive, and could place an animal in an energetic deficit (Van der Hoop et al., 2015). Stranded marine mammals frequently exhibit signs of previous fishery interaction, such as scarring or gear attached to their bodies, and the cause of death for many stranded marine mammals is often attributed to such interactions (Baird & Gorgone, 2005; Obusan et al., 2016). Because marine mammals that die or are injured in fisheries may not wash ashore and because not all animals that do wash ashore exhibit clear signs of interactions, stranding data probably underestimate fishery-related mortalities and injuries.

The overall impact of fisheries interactions can be seen in examples from the impact that has occurred to several species. From 1993 through 2003, 1,105 harbor porpoises were reported stranded from Maine to North Carolina, many of which had cuts and body damage suggestive of net entanglement (National Marine Fisheries Service, 2005b). In 1999 it was possible to determine that the cause of death for 38 of the stranded porpoises in that year were from fishery interactions (National Marine Fisheries Service, 2005b). An estimated 78 baleen whales were killed annually in the offshore Southern California/Oregon drift gillnet fishery during the 1980s (Heyning & Lewis, 1990). The Hawaiian Islands Large Whale Entanglement Response Network received more than 267 reports of large whales entangled in gear between the 2002 and 2014 seasons (Lyman, 2014). In southern California from 2010–2014, 78% of human-related cetacean strandings and 32% of human-related pinniped strandings were determined to be a result of fisheries interaction (Carretta et al., 2016).

2.2.2 Vessel Strike

Vessel strikes to marine mammals are another cause of mortality and stranding (Berman-Kowalewski et al., 2010; De Stephanis & Urquiola, 2006; Geraci & Lounsbury, 2005; Laist et al., 2001). An animal at the surface could be struck directly by a vessel, a surfacing animal could hit the bottom of a vessel, or an animal just below the surface could be cut by a vessel's propeller. The reasons that whales are struck by vessels are probably several fold, including acoustic shadowing of an approaching vessel (i.e., the vessel body interferes with sound from the propulsion unit propagating forward), complex acoustic propagation conditions, and vessels approaching at speeds where avoidance is difficult.

The severity of injuries typically depends on the size and speed of the vessel (Knowlton & Kraus, 2001; Laist et al., 2001; Vanderlaan & Taggart, 2007). An examination of all known ship strikes from all shipping sources (civilian and military) indicates vessel speed is a principal factor in whether a strike results in death (Jensen & Silber, 2003; Knowlton & Kraus, 2001; Laist et al., 2001; Vanderlaan & Taggart, 2007). In assessing records in which vessel speed was known, Laist et al. (2001) found a direct relationship between the occurrence of a whale strike and the speed of the vessel involved in the collision. The authors concluded that most deaths occurred when a vessel was traveling in excess of 13 knots. Jensen and Silber (2003) detailed 292 records of known or probable ship strikes of all large whale species from 1975 to 2002. Of these, vessel speed at the time of collision was reported for 58 cases. Of these cases, 39 (or 67 percent) resulted in serious injury or death. Operating speeds of vessels that struck various species of large whales ranged from 2 to 51 knots. The majority (79 percent) of these strikes occurred at speeds of 13 knots or greater. The average speed that resulted in serious injury or death was 18.6 knots. Pace and Silber (2005) found that the probability of death or serious injury increased rapidly with increasing vessel speed. Specifically, the predicted probability of serious injury or death increased from 45 percent to 75 percent as vessel speed increased from 10 to 14 knots, and exceeded 90 percent at 17 knots. Higher speeds during collisions result in greater force of impact, but higher speeds also appear to increase the chance of severe injuries or death by pulling whales toward the vessel. Computer simulation modeling showed that hydrodynamic forces pulling whales toward the vessel hull increase with increasing speed (Clyne & Kennedy, 1999; Knowlton et al., 1995; Silber et al., 2010).

2.2.3 Marine Mammal Viewing

Although considered by many to be a non-consumptive use of marine mammals with economic, recreational, educational, and scientific benefits, marine mammal watching is not without potential negative impacts. One concern is the disturbance from interactions with humans attempting to swim with wild marine mammals, such as was the case with Hawaiian spinner dolphins that were being disturbed while resting in shallow waters; NOAA published a proposed rule in 2016 to prevent such disturbances. Another concern is that animals become more vulnerable to vessel strikes once they habituate to vessel traffic (Swingle et al., 1993; Wiley et al., 1995). Additionally, habitats may be abandoned or adverse impacts may occur if disturbance levels are too high (Courbis & Timmel, 2009; Lusseau & Bejder, 2007; Noren et al., 2009; Stockin et al., 2008; Williams et al., 2006). Recorded marine mammal behavioral responses to whale-watching vessels varies greatly. The most common reactions noted include disruptions in activity budgets and path directionality, as well as increases in travel behaviors with less likelihood of resting or foraging behaviors (Meissner et al., 2015; Parsons, 2012; Senigaglia et al., 2016). Behaviors such as these in addition to potential avoidance, attraction, or indifference to whale-watching vessels likely depends on the complex interaction of many contextual factors such the distance of the vessel from the animal, vessel speed, vessel direction, vessel noise, the number of vessels as well as the animal's predisposition and prior experience (Au & Perryman, 1982; Erbe, 2002; Jansen et al., 2010; Magalhães et al., 2002; Nowacek et al., 2004; Richardson et al., 1995; Watkins, 1986; Williams et al., 2002; Würsig et al., 1998). Marine mammal viewing could impact energy expenditure and potentially the overall health of a marine mammal if these behaviors are sustained for long periods of time (Christiansen et al., 2014; Parsons, 2012).

2.2.4 Ingestion of Marine Debris

Debris in the marine environment is a hazard for many marine mammals. Debris may cause entanglement (see Section 2.2.1, Fisheries Interaction: Bycatch and Entanglement) and animals may also mistake plastics and other debris for food or incidentally consume it while foraging (Bortolotto et al., 2016; Denuncio et al., 2011; Fernández et al., 2009; Gall & Thompson, 2015; Jacobsen et al., 2010b; Lusher et al., 2015; National Oceanic and Atmospheric Administration Marine Debris Program, 2014; Stamper et al., 2006; Whitehead, 2003).Consumption of debris can lead to gastrointestinal blockage, satiation, and ulceration and is potentially fatal. However, the occurrence of and impact from individual animal's consumption of debris remains largely unknown (for review, see Baulch & Simmonds, 2015). From 1990 through October 1998, 215 pygmy sperm whales stranded along the U.S. Atlantic coast (New York to the Florida Keys) with the remains of plastic bags and other debris found in the stomachs of 13 of these animals (National Marine Fisheries Service, 2005c). In 2016, nine sperm whales that stranded in the North Sea also had traces of marine debris in their gastro-intestinal tracts (Unger et al., 2016). Twenty-eight percent of 106 incidentally captured Franciscana dolphins (*Pontoporia blainvillei*) had ingested plastic debris (Denuncio et al., 2011). Sperm whales are also known to ingest plastic debris (Whitehead, 2003), and this has occasionally led to mortality (Jacobsen et al., 2010a). Numerous other species of marine mammals are known to consume debris and plastics (Baird & Hooker, 2000; Fernández et al., 2009; Secchi & Zarzur, 1999; Stamper et al., 2006), but the scale to which this affects marine mammal populations is unknown.

2.2.5 Toxic Pollution

Research has demonstrated that high concentrations of potentially toxic substances (e.g., persistent organic pollutants, organochlorines used as pesticides, perfluorinated chemicals and polychlorinated biphenyls, mercury, and others) have been found in a many marine mammal species from a variety of locations around the world (Bachman et al., 2014; Bachman et al., 2015; Foltz et al., 2014; Fossi et al., 2004; Hall et al., 2006; Hansen et al., 2015; Hart et al., 2008; Hooker et al., 2007; Jepson & Law, 2016; Mearns et al., 2016; O'Hara et al., 1999; Reiner et al., 2016; Wintle et al., 2011). Research has indicated an increase in marine mammal diseases associated with bioaccumulation of these substances in some species (Hall et al., 2006; Tabuchi et al., 2006). Accumulation of these substances could lead to negative impacts in overall marine mammal health and may contribute to population declines (Bachman et al., 2014; Bachman et al., 2015; Hansen et al., 2015). Generally, the effects of contaminants are more likely to be indirect, potentially affecting prey species availability or increasing disease susceptibility (Geraci et al., 1999). In other more rare cases, anthropogenic events may have direct and detectable effects on marine mammals and their habitat, such as the 2010 Deep Water Horizon oil spill, which covered a vast area of the northern Gulf of Mexico for a period of approximately 3 months. An unusual mortality event, preliminarily involving 865 whales and dolphins, was declared in the northern Gulf of Mexico beginning in 2010 and extending into 2014 (NMFS, 2014). A series of research papers have been published since the oil spill documenting the impact of long-term oil exposure to bottlenose dolphins. In the years immediately following the oil spill, female bottlenose dolphins were found to experience a greater rate of *in utero* infections and late-term pregnancy failures (Colegrove et al., 2016); there was an overall lower reproductive success and increase in the mortality rate (Lane et al., 2015); and a higher incidence of bacterial pneumonia and evidence of adrenal atrophy were found (Venn-Watson et al., 2015). In addition, dolphins within the oil-exposed Barataria Bay showed an overall greater prevalence of disease conditions and generally poorer health relative to control populations (Schwacke et al., 2014).

2.2.6 Acute Noise Exposure

Over the past three decades, several mass stranding events have been associated with or speculated to be related to naval operations (D'Amico et al., 2009), seismic surveys (McGeady et al., 2016), and other anthropogenic activities that introduce sound into the marine environment (stranding event locations include the Canary Islands, Greece, Vieques, U.S. Virgin Islands, Madeira Islands, Haro Strait [Washington], Alaska, Hawaii, North Carolina). At sufficient levels, acute noise exposure may have the potential to either directly or indirectly contribute to stranding events, although the mechanism and causal link are not always apparent and may require additional study.

Both behavioral and physiological responses to acute noise exposure have been speculated as potential causes of stranding. At sufficient levels, acute noise exposure could result in panic, or the “fight or flight” response, resulting in marine mammals entering shallower water than they would normally enter. In social species, such responses may be exacerbated by social cohesion. From a physiological perspective, several direct causes of injury from acoustic exposure have been speculated, which could subsequently contribute to stranding. These include the resonance of tissues due to acoustic exposure, and acoustically mediated bubble formation.

A panel of government and private scientists was convened in 2002 to investigate the potential for acoustic resonance due to sonar exposure to have contributed to beaked whale strandings in the Bahamas (National Oceanic and Atmospheric Administration, 2002). The conclusions of the modeling group were that resonance of air-filled structures was not likely to have caused the Bahamas stranding because the frequencies at which resonance was predicted to occur were lower than those used by the Navy's mid-frequency sonar systems. Air cavity vibrations at resonant frequencies, where highest amplitude vibrations would occur, were considered insufficient to cause tissue damage, even under the worst-case scenarios modeled. For these reasons, the potential for acoustic resonance to contribute to strandings has been considered highly unlikely when realistic exposure conditions and biological structures are considered.

Gas and fat emboli in the blood vessels of stranded beaked whales were a novel finding of the 2002 Canary Island strandings, which was temporally and spatially associated with mid-frequency active sonar use (see Section 3.4, Canary Islands, September 24, 2002). Marine mammals are thought to deal with nitrogen loads in their blood and other tissues, caused by gas exchange from the lungs under conditions of high ambient pressure during diving, through anatomical, behavioral, and physiological adaptations (Hooker et al., 2012). Deep diving whales, such as beaked whales, normally have higher nitrogen loads in body tissues, which may make them more susceptible to decompression for certain modeled changes in dive behavior (Fahlman et al., 2014b; Fernández et al., 2005; Hooker et al., 2012; Jepson et al., 2003).

The possibility that the gas and fat emboli found by Fernández et al. (2005) was due to nitrogen bubble formation has been hypothesized to be related to either direct activation of the bubble by sonar signals or to a behavioral response in which the beaked whales flee to the surface following sonar exposure. The first hypothesis is related to rectified diffusion (Crum & Mao, 1996), the process of increasing the size of a bubble by exposing it to a sound field. This process is facilitated if the environment in which the ensonified bubbles exist is supersaturated with gas. Repetitive diving by marine mammals can cause the blood and some tissues to accumulate gas to a greater degree than is supported by the surrounding environmental pressure (Ridgway & Howard, 1979). Researchers have also considered the role of accumulation of carbon dioxide produced during periods of high activity by an animal, theorizing that accumulating carbon dioxide, which cannot be removed by gas exchange below the depth of lung collapse, may facilitate the formation of bubbles in nitrogen saturated tissues (Bernaldo de Quiros et al., 2012; Fahlman et al., 2014a). Deeper and longer dives of some marine mammals, such as those conducted by beaked whales, have been theoretically predicted to induce greater levels of supersaturation (Hooker et al., 2009; Houser et al., 2001), although other modeling efforts have suggested the situation is probably more complex and the relationship to diving depth not so simple (e.g., Fahlman et al., 2014b; Kvadsheim et al., 2012). For beaked whale strandings associated with sonar use, one theory is that observed bubble formation may be caused by long periods of compromised blood flow caused by the stranding itself (which reduces ability to remove nitrogen from tissues) following rapid ascent dive behavior that does not allow for typical management of nitrogen in supersaturated, long-halftime tissues (Houser et al., 2009). If rectified diffusion were possible in marine mammals exposed to high-level sound, conditions of tissue supersaturation could theoretically speed the rate and increase the size of bubble growth. Subsequent effects due to tissue trauma and emboli would presumably mirror those observed in humans suffering from decompression sickness. It is unlikely that the brief duration of sonar pings would be long enough to drive bubble growth to any substantial size without whales being immediately adjacent to the causative sound source. Indeed, follow-on work has demonstrated that for highly supersaturated tissues, exposure levels would necessarily be higher than is likely to occur in the real world (Crum et al., 2005). However, an alternative but related hypothesis has also been suggested: stable bubbles could be destabilized by high-level sound exposures such that bubble growth then occurs through static diffusion of gas out of the tissues. In such a scenario the marine mammal would need to be in a gas-supersaturated state long enough for bubbles to become of a problematic size. The second hypothesis speculates that rapid ascent to the surface following exposure to a startling sound might produce tissue gas saturation sufficient for the evolution of nitrogen bubbles (Fernández et al., 2005; Jepson et al., 2003). In this scenario, the rate of ascent would need to be sufficiently rapid to compromise behavioral or physiological protections against nitrogen bubble formation. Beaked whales that have been tagged have shown to ascend slowly in the beginning and middle of their ascent and more rapidly in the top 100 meters (m) where gas expansion is greatest. Due to the natural dive behavior of certain beaked whale species, the potential for decompression sickness exists (Tyack et al., 2006). It has been speculated that if repetitive shallow dives are used by beaked whales to avoid a predator or sound source, they could accumulate high levels of nitrogen because they would be above the depth of lung collapse (above about 210 feet [ft.]) which could lead to decompression sickness (Zimmer & Tyack, 2007).

Although theoretical predictions suggest the possibility for acoustically mediated bubble growth, there is considerable disagreement among scientists as to its likelihood and there is a lack of empirical data on gas kinetics in diving marine mammals (Hooker et al., 2012; Piantadosi & Thalmann, 2004). It has been argued that traumas from beaked whale strandings are consistent with gas emboli and bubble-induced tissue separations (Fernández et al., 2005; Jepson et al., 2003), but nitrogen bubble formation as the cause of the traumas has not been verified. Sound exposure levels predicted to cause in vivo bubble formation within diving cetaceans have not been evaluated and are suspected as needing to be very high (Crum et al., 2005). In contrast, in an analysis of sperm whale bones spanning 111 years, gas embolism symptoms were observed indicating that sperm whales may be susceptible to repetitive decompression sickness due to their natural diving behavior (Moore & Early, 2004). Additional work looking into the composition of cardiovascular and tissue bubbles in freshly stranded animals demonstrated a greater prevalence of nitrogen gas containing bubbles in deep diving species (Bernaldo de Quiros et al., 2012). However, the presence of bubbles postmortem, particularly after decompression, cannot be taken as indicative of bubble pathology (Bernaldo de Quiros et al., 2012; Bernaldo de Quiros et al., 2013a; Bernaldo de Quiros et al., 2013b; Dennison et al., 2011; Moore et al., 2009). Prior experimental work has also demonstrated the post-mortem presence of bubbles following decompression in laboratory animals can occur as a result of invasive investigative procedures (Stock et al., 1980), or from the presence of gas-forming bacteria in tissues of live animals (Bernaldo de Quiros et al., 2012; Bernaldo de Quiros et al., 2013a; Danil et al., 2014).

Stranding events associated or speculated to be associated with the use of naval sonar are detailed in the following two chapters.

3 STRANDING EVENTS ASSOCIATED WITH U.S. NAVY SONAR ACTIVITIES

This section analyzes stranding events in which U.S. Navy sonar was suspected of being associated with a marine mammal mass stranding. Most of the events involve a particular family of whales, the beaked whales. Beaked whale strandings have been reported since the 1800s (Cox et al., 2006; Geraci & Lounsbury, 2005; Podesta et al., 2006), the largest of which occurred in the 1870s in New Zealand when 28 Gray's beaked whales (*Mesoplodon grayi*) stranded. However, over the past two decades several mass strandings involving beaked whales have been coincident with naval operations that included active sonar (Cox et al., 2006; D'Amico et al., 2009; Filadelfo et al., 2009a; Frantzis, 1998; Jepson et al., 2003; Simmonds & Lopez-Jurado, 1991). Of the 126 beaked whale mass strandings reported between 1950 and 2004, 12 have coincided in time and space with naval activities that may have used mid-frequency active sonar, while 87 have no link to naval activities (D'Amico et al., 2009). Blainville's beaked whale (*Mesoplodon densirostris*) strandings are rare, and records show that one mass stranding was reported in 1989 in the Canary Islands. Cuvier's beaked whales (*Ziphius cavirostris*) are the most frequently reported beaked whale to strand, with 232 stranding events (both single and mass) totaling 316 animals reported in the Mediterranean Sea alone between 1803 and 2003 (Podesta et al., 2006).

D'Amico et al. (2009) reviewed global beaked whale mass strandings occurring between 1950 and 2004. The review suggested that 12 of 126 of the strandings could be considered to have coincided in space and time with naval activity that may have included active sonar use[1]. Training involving sonar has been conducted since World War II and the sonar systems in use today are the same output transducers in use since the 1970's (U.S. Department of the Navy, 2008). A number of potential mechanisms have been hypothesized to potentially explain the relationship between marine mammal strandings and mid-frequency active sonar activity. Among those receiving the most attention are a behavioral flight response to acoustic exposure that results in stranding or a flight response that results in the physiological consequence of inert bubble formation. Unfortunately, to date no definitive causal mechanisms by which mid-frequency active sonar could lead to the reported strandings and traumas has been made. Furthermore, why beaked whales seem to be particularly averse to sonar, but only in specific and relatively rare cases, has not been determined and is open to speculation.

While sonar may be a contributing factor to a small number of strandings under certain rare conditions, other contextual, geographical, physiological, or behavioral factors likely contribute to the necessary conditions for stranding to occur (D'Amico et al., 2009; Filadelfo et al., 2009a; Helble et al., 2016b; Manzano-Roth et al., 2016; Tyack, 2009; Tyack et al., 2011). In established Navy instrumented ranges, such as those in Hawaii and Southern California, where beaked whales are present and training and testing using sonar has been routine for decades, there have been no stranded beaked whales associated with sonar use (Filadelfo et al., 2009a; Filadelfo et al., 2009b). A review of past stranding events associated with sonar suggests the potential factors possibly contributing to a stranding event are steep bathymetric changes, narrow channels, multiple sonar ships, surface ducting and the presence of beaked whales that may be more adversely affected than other species to sonar and anthropogenic noise in general, particularly if populations are naïve to intensive sonar operations (D'Amico et al., 2009; Southall et al., 2007; Tyack, 2009).

The U.S. Navy closely coordinates with NMFS in the investigation of marine mammal strandings that are potentially associated with Navy sonar activities to better understand the events surrounding the strandings. The Navy has studied several stranding events in detail that may have occurred in association with Navy sonar activities. Information was collected on mass stranding events (events in which two or more cetaceans stranded) that have occurred and for which reports are available, from the past 40 years. Any causal agents that have been associated with those stranding events were also identified.

The following subsections discuss five specific stranding events that the U.S. Navy has agreed were associated in time and location with the use of sonar. Four of the five events occurred during North Atlantic Treaty Organization (NATO) training or testing where U.S. Navy presence was limited. One of the five events involved only U.S. Navy ships (Bahamas), the other four were multi-nation events. Of note, the total from these five events represent a small number of animals (50 cetaceans) since 1996 and most worldwide beaked whale strandings are not linked to naval sonar activity (D'Amico et al., 2009; International Council for the Exploration of the Sea, 2005; Podesta et al., 2006). A stranding of ten beaked whales in Crete coincident with naval exercises in 2014 is under review and has not yet been

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[1] Historical records documenting use of active sonar use in exercises prior to 2006 are not readily available, are inconsistent in the level of information provided when available, and are therefore not conclusive regarding the use of sonar. See D’Amico et al. (2009) for a discussion on the availability and ranking criteria for data in regard to these conclusions.

determined to be linked to sonar activities.

The following beaked whale stranding events have been associated with sonar activities:

May 1996	Greece (NATO/U.S.)
March 2000	Bahamas (U.S.)
May 2000	Portugal, Madeira Islands (NATO/U.S.)
September 2002	Spain, Canary Islands (NATO/U.S.)
January 2006	Spain, Mediterranean Sea coast (NATO/U.S.)

3.1 Greece, May 12–13, 1996

Description: Twelve Cuvier’s beaked whales (*Ziphius cavirostris*) stranded along a 38.2-kilometer (km) stretch of the coast of the Kyparissiakos Gulf on May 12 and 13, 1996 (Frantzis, 1998). From May 11 through May 15, the NATO lead research vessel Alliance was conducting sonar tests with signals of 600 hertz (Hz) and 3 kilohertz (kHz) and source levels (sound pressure level measured at 1 m from the source) of 228 and 226 decibels referenced to 1 micropascal (dB re 1 µPa), respectively (D'Amico, 1998; D'Spain et al., 2006). The timing and the location of the testing encompassed the time and location of the whale strandings (Filadelfo et al., 2005; Frantzis, 1998).

Findings: Partial necropsies of eight of the animals were performed, including external assessments and the sampling of stomach contents. No abnormalities attributable to acoustic exposure were observed, but the stomach contents indicated that the whales were feeding on cephalopods soon before the stranding event. Since beaked whale prey occur in deep water, the finding is suggestive of the beaked whales being present in deep water shortly prior to the event. No unusual environmental events before or during the stranding event could be identified (Frantzis, 1998).

Conclusions: The timing and spatial characteristics of this stranding event were atypical of stranding in Cuvier’s beaked whales, particularly in this region of the world. No natural phenomenon that might contribute to the stranding event could be identified that coincided in time with the mass stranding. Because of the rarity of mass strandings in the Greek Ionian Sea, the probability that the sonar tests and stranding were independent of one another was estimated as being extremely low (Frantzis, 1998). However, because information from the necropsies was incomplete and inconclusive, the cause of the stranding was not precisely determined.

3.2 Bahamas, March 15–16, 2000

Description: Seventeen marine mammals – nine Cuvier’s beaked whales, three Blainville’s beaked whales (*Mesoplodon densirostris*), two unidentified beaked whales, two minke whales (*Balaenoptera acutorostrata*), and one spotted dolphin (*Stenella frontalis*) – stranded along the northeast and northwest Providence Channels of the Bahamas Islands on March 15–16, 2000 (U.S. Department of Commerce & U.S. Department of the Navy, 2001). The strandings occurred over a 36-hour period and coincided with U.S. Navy use of mid-frequency active sonar within the channel. Navy ships were involved in tactical sonar exercises for approximately 16 hours on March 15, 2000. The ships, which operated hull-mounted sonar, moved through the channel while emitting sonar pings approximately every 24 seconds. The timing of pings was staggered between ships. The nominal source levels of these sonar systems have sound pressure levels of 235 dB re 1 µPa and 223 dB re 1 µPa. The center frequency of pings was 3.3 kHz and 6.8 to 8.2 kHz, respectively.

Seven of the animals that stranded died, while ten animals were returned to the water alive. The animals known to have died included five Cuvier’s beaked whales, one Blainville’s beaked whale, and the single spotted dolphin. Six necropsies were performed and three of the six necropsied animals (one

Cuvier's beaked whale, one Blainville's beaked whale, and the spotted dolphin) were fresh enough to permit identification of pathologies by computed tomography. Tissues from the remaining three animals were in a state of advanced decomposition at the time of inspection.

Findings: The spotted dolphin demonstrated poor body condition and evidence of a systemic debilitating disease. In addition, since the dolphin stranding site was isolated from the acoustic activities of Navy ships, it was determined that the dolphin stranding was unrelated to the presence of Navy active sonar.

All five necropsied beaked whales were in good body condition and did not show any signs of external trauma or disease (U.S. Department of Commerce & U.S. Department of the Navy, 2001). In the two best preserved whale specimens, hemorrhage was associated with the brain and hearing structures. Specifically, subarachnoid hemorrhage within the temporal region of the brain and intracochlear hemorrhages were noted. Similar findings of bloody effusions around the ears of two other moderately decomposed whales were consistent with the same observations in the freshest animals. In addition, three of the whales had small hemorrhages in their acoustic fats, which are fat bodies used in sound production and reception (i.e., fats of the lower jaw and the melon). The best-preserved whale demonstrated acute hemorrhage within the kidney, inflammation of the lung and lymph nodes, and congestion and mild hemorrhage in multiple other organs. Other findings were consistent with stresses and injuries associated with the stranding process. These consisted of external scrapes, pulmonary edema and congestion.

Conclusions: The post-mortem analyses of stranded beaked whales led to the conclusion that the immediate cause of death resulted from overheating, cardiovascular collapse and stresses associated with being stranded on land (U.S. Department of Commerce & U.S. Department of the Navy, 2001). However, subarachnoid and intracochlear hemorrhages were believed to have occurred prior to stranding and were hypothesized as being related to an acoustic event. Passive acoustic monitoring records demonstrated that no large scale acoustic activity besides the Navy sonar exercise occurred in the times surrounding the stranding event. The mechanism by which sonar could have caused the observed traumas or caused the animals to strand was undetermined. The spotted dolphin was in overall poor condition for examination, but showed indications of long-term disease. No analysis of baleen whales (minke whale) was conducted. Baleen whale stranding events have not been associated with either low-frequency or mid-frequency sonar use (International Council for the Exploration of the Sea, 2005).

3.3 Portugal, May 10–14, 2000

Description: Three Cuvier's beaked whales stranded on two islands in the Madeira Archipelago, Portugal, from May 10–14, 2000 (Cox et al., 2006; Freitas, 2004). A joint NATO amphibious training exercise, named "Linked Seas 2000," which involved participants from 17 countries, took place in Portugal during May 2–15, 2000. The timing and location of the exercises overlapped with that of the stranding incident.

Findings: Two of the three whales were necropsied. Two heads were taken to be examined. One head was intact and examined grossly and by computed tomography; the other was only grossly examined because it was partially flensed (to strip the blubber or skin) and had been seared from an attempt to dispose of the whale by fire (Ketten, 2005).

No blunt trauma was observed in any of the whales. Consistent with prior computed tomography scans of beaked whales stranded in the Bahamas 2000 incident, one whale demonstrated subarachnoid and peribullar hemorrhage and blood within one of the brain ventricles. Post-cranially, the freshest whale demonstrated renal congestion and hemorrhage, which was also consistent with findings in the freshest specimens in the Bahamas incident.

Conclusions: The pattern of injury to the brain and auditory system were similar to those observed in the Bahamas strandings, as were the kidney lesions and hemorrhage and congestion in the lungs (Ketten, 2005). The similarities in pathology and stranding patterns between these two events suggested a similar causative mechanism. Although the details about whether or how sonar was used during "Linked Seas 2000" is unknown, the presence of naval activity within the region at the time of the strandings suggested a possible relationship to Navy activity.

3.4 Canary Islands, September 24, 2002

Description: On September 24, 2002, 14 beaked whales stranded on Fuerteventura and Lanzarote Islands in the Canary Islands. Seven of the 14 whales died on the beach and the other seven were returned to the ocean. Four beaked whales were found stranded dead over the next 3 days either on the coast or floating offshore (Fernández et al., 2005). At the time of the strandings, an international naval exercise, Neo-Tapon 2002, which involved numerous surface warships and several submarines was being conducted off the coast of the Canary Islands. Tactical mid-frequency active sonar was utilized during the exercises, and strandings began within hours of the onset of the use of mid-frequency active sonar (Fernández et al., 2005).

Findings: Eight Cuvier's beaked whales, one Blainville's beaked whale, and one Gervais' beaked whale were necropsied; six of them within 12 hours of stranding (Fernández et al., 2005). The stomachs of the whales contained fresh and undigested prey contents. No pathogenic bacteria were isolated from the whales, although parasites were found in the kidneys of all of the animals. The head and neck lymph nodes were congested and hemorrhages were noted in multiple tissues and organs, including the kidney, brain, ears, and jaws. Widespread fat emboli were found throughout the carcasses, but no evidence of blunt trauma was observed in the whales. In addition, the parenchyma of several organs contained macroscopic intravascular bubbles and lesions, putatively associated with nitrogen off-gassing.

Conclusions: The association of NATO mid-frequency sonar use close in space and time to the beaked whale strandings, and the similarity between this stranding event and previous beaked whale mass strandings coincident with sonar use, suggests that a similar scenario and causative mechanism of stranding may be shared between the events. Beaked whales stranded in this event demonstrated brain and auditory system injuries, hemorrhages, and congestion in multiple organs, similar to the pathological findings of the Bahamas and Madeira stranding events. In addition, the necropsy results of the Canary Islands stranding event lead to the hypothesis that the presence of disseminated and widespread gas bubbles and fat emboli were indicative of nitrogen bubble formation, similar to what might be expected in decompression sickness (Fernández et al., 2005; Jepson et al., 2003). Whereas gas emboli would develop from the nitrogen gas, fat emboli would enter the blood stream from ruptured fat cells (presumably where nitrogen bubble formation occurs) or through the coalescence of lipid bodies within the blood stream.

3.5 Spain, January 26–27, 2006

Description: The Spanish Cetacean Society reported an atypical mass stranding of four beaked whales that occurred January 26–28, 2006, on the southeast coast of Spain near Mojacar (Gulf of Vera) in the western Mediterranean Sea. According to the report, two of the whales were discovered the evening of January 26 and were found to be still alive (Arbelo et al., 2008). Two other whales were discovered on January 27, but had already died.

From January 25–26, 2006, a NATO surface ship group (seven ships including one U.S. ship under NATO operational command) conducted active sonar training against a Spanish submarine within 50 nautical miles (NM) of the stranding site.

Findings: Veterinary pathologists necropsied the two male and two female beaked whales (*Z. cavirostris*). The whales demonstrated findings grossly similar to those necropsied following the Canary Islands event of 2002; venous gas embolism and diffuse congestion was found concomitant with hemorrhage, particularly in association with acoustic jaw fats, and the brain, ears and kidneys. Fat emboli were also noted in the vessels and parenchyma of some organs.

Conclusions: According to Arbelo et al. (2008), a likely cause of this type of beaked whale mass stranding event may have been anthropogenic acoustic activities. However, no detailed pathological results confirming this supposition have been published to date, and no positive acoustic link was established as a direct cause of the stranding.

4 STRANDINGS SPECULATED BUT NOT LINKED TO U.S. NAVY SONAR ACTIVITIES

The following sections present marine mammal strandings which were thought to be possibly linked to U.S. Navy sonar activities, but have been studied and no link has been found. As detailed in the individual case study conclusions below, the U.S. Navy believes there is enough evidence available to refute allegations of impacts from mid-frequency active sonar or indicate a substantial degree of uncertainty that precludes a meaningful scientific conclusion.

4.1 Washington, May 2–June 2, 2003

Description: At 10:40 am on May 5, 2003, the USS SHOUP began the use of tactical mid-frequency active sonar as part of a naval exercise. At 2:20 pm, the USS SHOUP entered the Haro Strait and terminated active sonar use at 2:38 pm. Between May 2 and June 2, 2003, approximately 16 strandings involving 15 harbor porpoises (*Phocoena phocoena*) and one Dall's porpoise (*Phocoenoides dalli*) had been reported to the Northwest Marine Mammal Stranding Network. A comprehensive review of all strandings and the events involving USS SHOUP on May 5, 2003 were presented by the Department of the Navy (U.S. Department of the Navy, 2003). Given that the USS SHOUP was known to have operated sonar in the strait on May 5, and that behavioral reactions of killer whales (*Orcinus orca*) had been supposedly linked to these sonar operations (National Marine Fisheries Service, 2005a), NMFS undertook an analysis of whether sonar caused the strandings of the harbor porpoises.

Whole carcasses of ten harbor porpoises and the head of an additional porpoise were collected for analysis. Necropsies were performed on ten of the porpoises, although only six of the ten were whole carcasses, and two heads were selected for computed tomographic imaging. Gross examination, histopathology, age determination, blubber analysis, and various other analyses were conducted on each of the carcasses (Norman et al., 2004).

Findings: Post-mortem findings and analysis details are found in Norman et al. (2004). All of the carcasses suffered from some degree of freeze-thaw artifact that hampered gross and histological evaluations. At the time of necropsy, three of the porpoises were moderately fresh, whereas the remainder of the carcasses were considered to have moderate to advanced decomposition. None of the 11 harbor porpoises demonstrated signs of acoustic trauma. In contrast, a putative cause of death was determined for five of the porpoises; two animals had blunt trauma injuries and three animals had indication of disease processes (fibrous peritonitis, salmonellosis, and necrotizing pneumonia). A cause of death could not be determined in the remaining animals, which is consistent with the expected percentage of marine mammal necropsies conducted within the northwest region. It is important to note, however, that these determinations were based only on the evidence from the necropsy to avoid bias with regard to determinations of the potential presence or absence of acoustic trauma. For example, the investigators had no knowledge of other potential external causal factors, such as one porpoise having been found tangled in a fishing net, which may have assisted in their determination regarding the likely cause of death.

Conclusions: Seven of the porpoises collected and analyzed were determined to have died prior to USS SHOUP departing to sea on May 5, 2003. Several of these porpoises were discovered prior to May 5. One was discovered on May 5, 2003, but was in a state of moderate decomposition indicating it died before May 5; the cause of death was determined, most likely, to be *Salmonella septicemia*. Another porpoise, discovered at Port Angeles on May 6, 2003, was in a state of moderate decomposition, indicating that this porpoise also died prior to 5 May. One stranded harbor porpoise discovered fresh on May 6 is the only animal that could potentially be linked in time to the USS SHOUP’s May 5 active sonar use. Necropsy results for this porpoise found no evidence of acoustic trauma. The remaining eight strandings were discovered one to three weeks after the USS SHOUP’s May 5 transit of the Haro Strait, making it difficult to causally link the sonar activities of the USS SHOUP to the timing of the strandings. Two of the eight porpoises died from blunt trauma injury and a third suffered from parasitic infestation, which possibly contributed to its death (Norman et al., 2004). For the remaining five porpoises, NMFS was unable to identify the causes of death. It is important to note that in the years since the USS SHOUP incident, annual numbers of stranded porpoises not only increased, but also showed similar causes of death (when determinable) to the causes of death noted in the USS SHOUP investigation (Huggins et al., 2015).

NMFS concluded from a retrospective analysis of stranding events that the number of harbor porpoise stranding events in the approximate month surrounding the USS SHOUP use of sonar was higher than expected based on annual strandings of harbor porpoises (Norman et al., 2004). NMFS acknowledged that the intense level of media attention to the strandings likely resulted in increased reporting effort by the public over that which is normally observed (Norman et al., 2004). NMFS also noted in its report that the “sample size is too small and biased to infer a specific relationship with respect to sonar usage and subsequent strandings.” It was later determined by NMFS that the number of harbor porpoise strandings in the northwest increased beginning in 2003 and through 2006. On November 3, 2006, an unusual mortality event in the Pacific Northwest was declared. Figure 4-1 shows the number of strandings documented in the northwest for harbor porpoises. In 2006, a total of 66 harbor porpoise strandings were reported in the outer coast of Oregon and Washington and inland waters of Washington (National Oceanic and Atmospheric Administration, 2009; National Oceanic and Atmospheric Administration Fisheries Northwest Region, 2006). An increase in harbor porpoise strandings in subsequent years (through 2009), however, has led to the conclusion that the increase in observed strandings is likely related to changes in harbor porpoise populations and an increased effort in the reporting of strandings (Huggins et al., 2015), i.e., the designation of an unusual mortality event may not be warranted. Therefore, the higher number of strandings in 2003 were likely indicative of a start to a multi-year trend in increased strandings related to an increase in local harbor porpoise population sizes, and since little post-mortem evidence for acoustic trauma exists, it is likely the porpoises stranded around the time of USS SHOUP tactical sonar operations were unrelated to acute acoustic trauma from sonar exposure.

The speculative association of the harbor porpoise strandings to the use of sonar by the USS SHOUP was inconsistent with prior stranding events linked to the use of mid-frequency active sonar. Specifically, in prior events, the stranding of whales occurred over a short period of time (less than 36 hours), stranded individuals were spatially co-located, traumas in stranded animals were consistent between events, and active sonar was known or suspected to be in use. Although mid-frequency active sonar was used by the USS SHOUP, the distribution of harbor porpoise strandings by location and with respect to time surrounding the event do not support the suggestion that mid-frequency active sonar was a cause of harbor porpoise strandings. Rather, a lack of evidence of any acoustic trauma within the harbor porpoises, and the identification of probable causes of stranding or death in several animals, supports the conclusion that harbor porpoise strandings were unrelated to the sonar activities of the USS SHOUP.

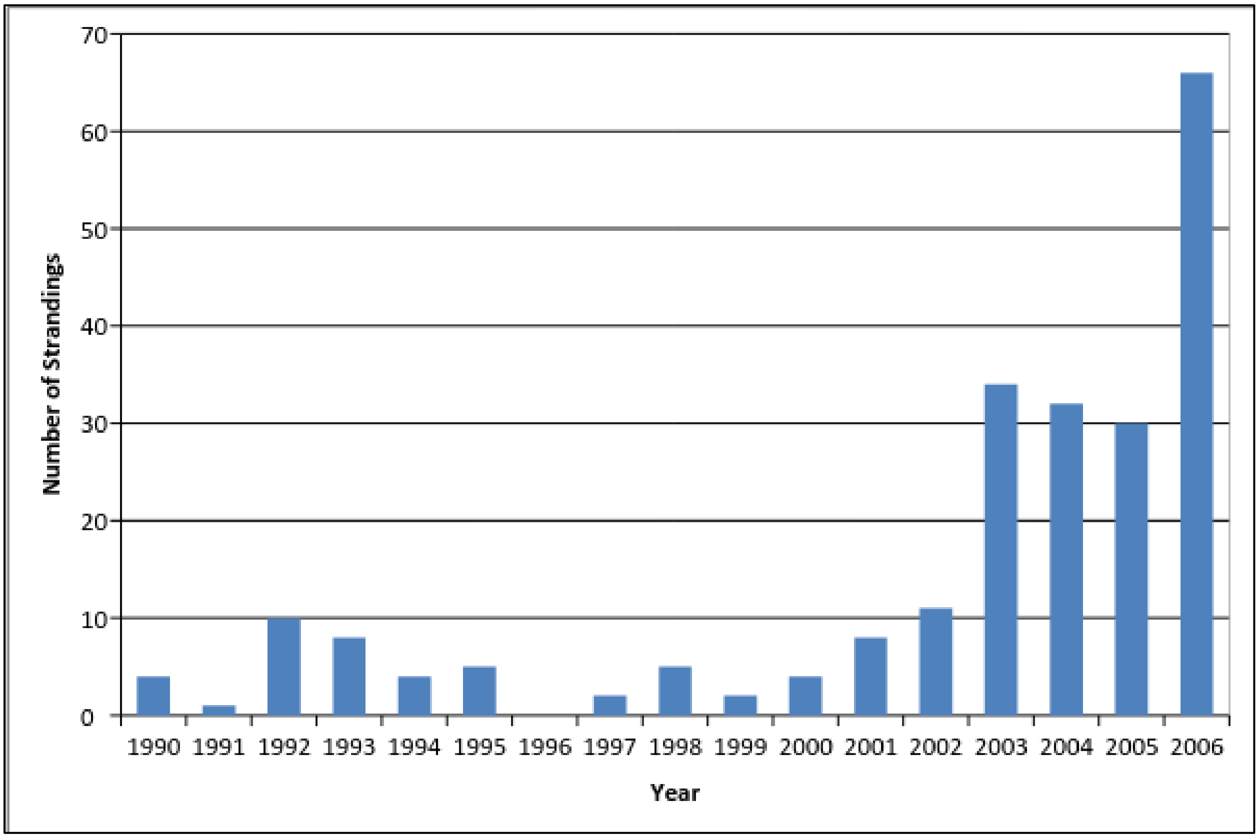

Figure 4-1: Northwest Region Harbor Porpoise Strandings 1990–2006
Source: National Oceanic and Atmospheric Administration Fisheries Northwest Region (2006)

4.2 Alaska, June 7–July 19, 2004

Description: In spring 2004, two Cuvier's beaked whales were discovered stranded at two separate locations along the Alaskan coastline (26 February at Yakutat and 1 June at Nuka Bay). From June 7 to 16, 2004 Navy conducted an exercise called Alaska Shield/Northern Edge. Between June 27 and July 19, 2004, five beaked whales were discovered at various locations along 1,600 miles (2,625 km) of the Alaskan coastline and one was found floating (dead) at sea. The whales onshore included three Baird's beaked whales (*Berardius bairdii*) and two Cuvier's beaked whales. Information regarding the strandings was incomplete as the whales had been dead for some time before they were discovered and were in moderate to advanced states of decomposition so necropsies were not performed.

Findings: Information regarding the strandings is incomplete as the whales had been dead for some time before they were discovered. The stranded beaked whales were in moderate to advanced states of decomposition and necropsies were not performed. Additionally, prior to the Navy conducting the Alaska Shield/Northern Edge exercise, two Cuvier's beaked whales were discovered stranded at two separate locations along the Alaskan coastline (February 26 at Yakutat and June 1 at Nuka Bay).

Records gathered by Zimmerman (1991) for the period between 1975 and 1987 indicate that 325 stranded cetaceans were reported for the entire state of Alaska including 29 Stejneger's beaked whales (*Mesoplodon stejnegeri*), 19 Cuvier's beaked whales, and 8 Baird's beaked whales. Cuvier's beaked whales had been found stranded from the eastern Gulf of Alaska to the western Aleutians. Baird's beaked whales were found stranded as far north as the area between Cape Pierce and Cape Newenham, east near Kodiak, and along the Aleutian Islands. The stranding of beaked whales in Alaska is a relatively uncommon occurrence when compared to other species.

Conclusions: The at-sea portion of the Alaska Shield/Northern Edge 2004 exercise consisted mainly of surface ships and aircraft tracking a vessel of interest which was then followed by a vessel boarding search and seizure event. There was no anti-submarine warfare component to the exercise and no use of mid-frequency active sonar. There were no acoustic events in the Alaska Shield/Northern Edge exercise that could have caused or been related to the strandings over this 33 day period and spread along 1,600 miles of Alaskan coastline.

4.3 Hawaii, July 3–4, 2004

Description: The majority of the following information is taken from the NMFS report (Southall et al., 2006) but includes additional and new information not presented in the NMFS report. At approximately 7:00 a.m. on July 3, 2004, between 150 and 200 melon-headed whales (*Peponocephala electra*) were observed entering Hanalei Bay, Kauai by individuals attending a canoe blessing ceremony. The whales were reported entering the bay in a "wave as if they were chasing fish" (Southall et al., 2006). At 6:45 a.m. on July 3, approximately 25 NM north of Hanalei Bay, active sonar had been tested briefly prior to the start of an anti-submarine warfare exercise that was part of the broader Rim of the Pacific (RIMPAC) naval exercise. At 8:00 a.m., approximately an hour after the whales entered Hanalei Bay, Kauai antisubmarine warfare exercises were initiated.

The whales stopped in the southwest portion of the bay, grouping tightly, and displayed spy-hopping and tail-slapping behavior. As people went into the water among the whales, the pod separated into as many as four groups, with individual animals moving among the people in clusters. This continued through most of the day, with the animals slowly moving south and then southeast within the bay. By about 3:00 p.m., the police arrived and began restricting people from entering the water and interacting with the animals as had been occurring for approximately 8 hours. At 4:45 p.m. on July 3 the RIMPAC Battle Watch Captain received a call from a NMFS representative in Honolulu, Hawaii, reporting the sighting of as many as 200 melon-headed whales in Hanalei Bay. At 4:47 p.m. the Battle Watch Captain directed all ships in the area to cease active sonar transmissions.

At 7:20 p.m. on July 3, the whales were observed in a tight single pod 75 yards from the southeast side of the bay. The pod was circling in a group and displayed frequent tail slapping and whistle vocalizations and some spy hopping. No predators were observed in the bay and no animals were reported as having fresh injuries. The pod stayed in the bay through the night of 3 July. On the morning of 4 July the whales were observed to still be in the bay and collected in a tight group. A decision was made at that time to attempt to herd the animals out of the bay. A 700-to-800-ft. rope was constructed by weaving together beach morning glory vines. This vine rope was tied between two canoes and with the assistance of 30 to

40 kayaks, was used to herd the animals out of the bay. By approximately 11:30 a.m. on July 4, the pod was guided out of the bay.

A single neonate melon-headed whale was observed in the bay on the afternoon of July 4 after the whale pod had left the bay. The following morning on July 5, the neonate was found stranded on Lumahai Beach. It was pushed back into the water but was found stranded dead between 9 and 10 a.m. near the Hanalei pier. NMFS collected the carcass and had it shipped to California for necropsy, tissue collection, and diagnostic imaging.

Following the unusual milling event, NMFS undertook an investigation of possible causative factors of the event (Southall et al., 2006). This analysis included available information on environmental factors, biological factors, and an analysis of the potential for sonar involvement. The latter analysis included vessels that utilized mid-frequency active sonar on the afternoon and evening of July 2 (the day before the whales entered the bay) when they were located many miles to the southeast of Kauai, on the opposite side of the island from Hanalei Bay.

Findings: The NMFS report concluded that sonar use was a “plausible, if not likely, contributing factor in what may have been a confluence of events” (Southall et al., 2006). NMFS suggested from the acoustic analysis that the melon-headed whales would have had to have been on the southeast side of Kauai on 2 July to have been exposed to sonar from naval vessels the day before the “mass stranding” (Southall et al., 2006). There was no indication whether the animals were in that region or whether they were elsewhere on July 2. NMFS concluded that the animals would have had to react to the sonar, swim from 1.4-4.0 m/s for 6.5 to 17.5 hours after sonar transmissions ceased on July 2 swim along the coast of Kauai, and enter the near-shore area of the bay to be observed in Hanalei Bay by 7:00 a.m. on July 3. Sound transmissions by ships to the north of Hanalei Bay on July 3 were produced as part of exercises between 6:45 a.m. and 4:47 p.m. Propagation analysis conducted by the Navy estimated that the level of sound from these transmissions at the mouth of Hanalei Bay could have ranged from 138-149 dB re 1 µPa SPL; however, there was no means by which it could be determined if the sonar was even directed towards the bay at this time. NMFS postulated that while sonar from July 2 could have caused the animals to end up in Hanalei Bay, sonar use on July 3 could have caused them to stay in the bay and lead to the milling behavior observed.

NMFS was unable to determine any environmental factors (e.g., harmful algal blooms, weather conditions, prey) that may have contributed to the stranding. Later analysis suggested that a full moon the evening before the stranding coupled with a squid run (Mobley et al., 2006) may have contributed. This would be consistent with the first observations of the whales entering the bay in a line “as if chasing fish” (Southall et al., 2006).

There was one mortality associated with this event. A necropsy of the stranded melon-headed whale calf suggested that the animal died from a lack of nutrition, possibly following separation from its mother. The calf was estimated to be approximately one week old. Although the calf appeared not to have eaten for some time, it was not possible to determine whether the calf had ever nursed after it was born. The calf showed no signs of blunt trauma or viral disease and had no indications of acoustic injury.

Conclusions: Although it is not impossible, it is unlikely that sonar caused the melon-headed whales to enter Hanalei Bay or resulted in the behaviors noted. This conclusion is based on a number of factors:

1. Speculation that the whales may have been exposed to sonar the day before (July 2) and then fled around Kauai and into Hanalei Bay is not supported by reasonable expectation of animal behavior and sustained swim speeds, especially given the presence of a newborn calf. The flight response of

whales persisting for some time after exposure have been documented (Sivle et al., 2015). However, the swim speeds, though feasible for the species, are highly unlikely to be maintained for the durations proposed, particularly since the pod was a mixed group containing both adults and neonates. Whereas adults may maintain a swim speed of 4.0 m/s for some time, it is improbable that a neonate could achieve the same for a period of many hours.

2. The area between the islands of Oahu and Kauai and the Pacific Missile Range Facility training range north of Kauai have been used in RIMPAC exercises for more than 30 years, and are used year-round for anti-submarine warfare training with mid-frequency active sonar. Melon-headed whales inhabiting the waters around Kauai are likely not naive to the sound of sonar and there has never been another stranding event associated in time with anti-submarine warfare training at Kauai. Similarly, the waters surrounding Hawaii contain an abundance of marine mammals, many of which would have been exposed to the same sonar operations that were speculated to have affected the melon-headed whales. No other strandings were reported coincident with the RIMPAC exercises. This leaves no explanation as to why melon-headed whales would respond to this instance of sonar use by swimming into a confined bay many miles from and many hours after the exposure.
3. At the nominal swim speed for melon-headed whales, the whales had to be within 1.5 to 2 NM of Hanalei Bay before sonar was activated on July 3. The whales would have had to be close to shore instead of in their open ocean habitat at 6:45 a.m. when the sonar was activated to have been observed inside Hanalei Bay from the beach by 7:00 a.m. This observation suggests that other potential factors could have caused the event (see below).
4. The report issued by NMFS (Southall et al., 2006) indicated the behavior of the melon-headed whales in Hanalei was unusual. The only record for out of habitat melon-headed whales in Hawaii was briefly mentioned in a narrative from the Wilkes' Expedition in the 1840s where a pod was discovered near-shore at Hilo Bay and then driven onshore for consumption (see Brownell et al., 2009). The Navy believes that the behaviors in general and the "abnormal" milling behavior observed that day was more likely the result of people and boats in the water around the whales at Hanalei for approximately 8 hours rather than the result of sonar activities taking place 25 or more miles off the coast to the northwest. Brownell and colleagues concluded that the milling behavior observed in the whales in Hanalei Bay was typical of that seen prior to mass stranding events and that the behavior was dissimilar to observations of other melon-headed whale populations resting in shallow areas during the day (Brownell et al., 2009). However, many hours passed after the Hanalei milling behavior was observed and no stranding (animals on the beach) occurred, except for the neonate discovered the following day. Furthermore, in characterizing the behaviors observed at Hanalei Bay, including the milling behavior, Southall et al. (2006) and Brownell et al. (2009) did not consider the potential effect from hours of interaction between the whales and the public before the police arrived and restricted those activities, which may have caused or influenced the behaviors observed.
5. On the same morning as the 2004 Hanalei stranding, 500 to 700 melon-headed whales and Risso's dolphins also entered into Sasanhaya Bay, Rota, in the Northern Marianas Islands (Jefferson et al., 2006) which suggests that there may be a common factor which prompted the melon-headed whales to approach the shoreline. A full moon occurred the evening before the stranding, which could have caused squid (a prey species for melon-headed whales) to migrate into shallower waters (Mobley et al., 2006). Thus, it is possible that the melon-headed whales were capitalizing on a lunar event that provided an opportunity for relatively easy prey capture (Mobley et al., 2006). Brownell et al. (2009) disputed this hypothesis, noting that melon-headed whales rest near-shore during the

day and feed offshore in deeper water at night near many oceanic islands and that the Rota event was normal diurnal resting behavior, which has also been documented at Palmyra.

6. The underwater noise levels at the entrance to the bay were estimated to roughly range in sound pressure level from 95 to 149 dB re 1 µPa. This estimation assumes the sonar was directed towards the bay, a homogeneous water column, no blockage of the sound from any fringing reef, and no sound absorption by the bay's sandy bottom. Received levels as a function of time of day have not been reported, so it is not possible to determine when the presumed highest levels would have occurred and for how long. However, received levels in the upper range could have been audible by human observers in the bay. The statement by one interviewee that he heard "pings" that lasted an hour and that they were loud enough to hurt his ears is unreliable. Received levels necessary to cause pain over the duration stated would have been observed by most individuals in the water with the animals. No other such reports were obtained from people interacting with the animals in the water.
7. There was a near mass stranding (animals milling out of their habitat) of 300 to 350 melon-headed whales in Manila Bay (Bataan), Philippines in February 2009 (Aragones et al., 2010). Pictures of the event depict grouping behavior like that displayed at Hanalei Bay in July 2004. No naval sonar activity was noted in the area, although it was suspected by the authors, based on personal communication with a government fisheries representative, that dynamite blasting in the area, may have occurred within the days prior to the event (Aragones et al., 2010). However, the dynamite blasting had occurred in this area without report of this behavior. Although melon-headed whales entering embayments may be infrequent and rare, there is precedent for this type of occurrence on other occasions in the absence of naval activity.

Summary – Although NMFS concluded that sonar use was a "plausible, if not likely, contributing factor in what may have been a confluence of events" (Southall et al., 2006), this conclusion was primarily based on the abnormal behavior of the whales and the absence of other compelling explanations. The authors of the NMFS report on the incident were unaware, at the time of publication, of the simultaneous event in Rota or the subsequent occurrence of a similar event in the Philippines. While clearly a rare event, in light of the simultaneous Rota event and a similar subsequent event in the Philippines (neither of which involved sonar use), the Hanalei event does not appear as unique as initially presented and the suggestion that sonar was causative or a contributing factor is weakened. It remains questionable how plausible or likely was a suggested scenario involving melon-headed whales swimming for hours to enter Hanalei Bay on July 3, 2004, as a result of sonar exposure from the night before. The Hanalei Bay incident does not share the characteristics observed with other mass strandings of whales coincident with sonar activity (e.g., specific traumas, species composition, etc.). The one mortality that occurred on July 5 was a week-old calf that died following separation from its mother, possibly as a result of the pod being herded out of the bay on July 4. The general lack of knowledge on what constitutes normal behavior and an inability to conclusively link or exclude the impact of other environmental factors makes the "contributing factor" link between sonar and the melon-headed whale event highly speculative at best.

4.4 Japan, 1980–2004

Description: A comparison of the historical occurrence of beaked whale strandings in Japan (where there are U.S. naval bases), with strandings in New Zealand (which lacks a U.S. naval base) concluded the higher number of strandings in Japan may be related to the presence of the U.S. Navy vessels using mid-frequency active sonar (Brownell et al., 2004). While the dates for the strandings were well documented, no correlation with the dates of Navy activities or exercises with the stranding dates was performed. Filadelfo et al. (2009a) and D'Amico et al. (2009) looked at past U.S. Navy exercise schedules from 1980 to 2004 for the water around Japan in comparison to the dates for the strandings provided by Brownell et al. (2004). None of the strandings occurred during or soon (within weeks) after any U.S. Navy exercises. In contrast to the proposition by Brownell et al. (2004), these latter studies found no correlation between the strandings and Navy exercises in the waters surrounding Japan.

4.5 North Carolina, January 15–16, 2005

Description: On January 15 and 16, 2005, 36 marine mammals consisting of 33 short-finned pilot whales, one minke whale, and two dwarf sperm whales stranded alive on the beaches of North Carolina (Hohn et al., 2006). The animals were scattered across a 111-km area from Cape Hatteras northward. Because of the live stranding of multiple species, the event was classified as an unusual mortality event. It is the only stranding on record for the region in which multiple offshore species were observed to strand within a 2- to 3-day period.

The U.S. Navy indicated that from January 12–14, 2005, some unit level training with mid-frequency active sonar was conducted by vessels that were 93 to 185 km from Oregon Inlet, North Carolina. An expeditionary strike group was also conducting exercises to the southeast, but the closest point of active sonar transmission from the strike group to the inlet was 650 km away. The unit level operations were not unusual for the area or time of year and the vessels were not involved in anti-submarine warfare exercises. Marine mammal observers onboard the vessels did not detect any marine mammals during the period of unit level training. No sonar transmissions were made on January 15–16, 2005.

The National Weather Service reported that a severe weather event moved through North Carolina on January 13 and 14. The event was caused by an intense cold front that moved into an unusually warm and moist air mass that had been persisting across the eastern United States for about a week. The weather caused flooding in the western part of the state, considerable wind damage in central regions of the state, and at least three tornadoes that were reported in the north central part of the state. The presence of severe weather is important and is a suspected contributor to stranding events (see Section 2.1.4, Weather Events and Climate Influences); for example, on a previous occasion it was determined that hurricanes were likely responsible for mass strandings of Gervais' beaked whales in North Carolina and pygmy killer whales in the British Virgin Islands (Mignucci-Giannoni et al., 2000; Norman & Mead, 2001).

Over a 2-day period (January 16 and 17), 2 dwarf sperm whales, 27 pilot whales, and the minke whale were necropsied and tissue samples collected. Twenty-five of the stranded cetacean heads were examined; two pilot whale heads and the heads of the dwarf sperm whales were analyzed by computed tomography.

Findings: The pilot whales and dwarf sperm whales were not emaciated, but the minke whale, which was believed to be a dependent calf, was emaciated. Many of the animals were on the beach for an extended period of time prior to necropsy and sampling, and many of the biochemical abnormalities noted in the animals were suspected of being related to the stranding and prolonged time on land. Lesions were observed in all of the organs, but there was no consistency across species. Musculoskeletal disease was observed in two pilot whales and cardiovascular disease was observed in one dwarf sperm whale and one pilot whale. Parasites were a common finding in the pilot whales and dwarf sperm whales but were considered consistent with the expected parasite load for wild odontocetes. None of the animals exhibited traumas similar to those observed in prior stranding events associated with mid-frequency active sonar activity. Specifically, there was an absence of auditory system trauma and no evidence of distributed and widespread bubble lesions or fat emboli, as was previously observed

(Fernández et al., 2005).

Sonar transmissions prior to the strandings were limited in nature and did not share the concentration identified in previous events associated with mid-frequency active sonar use (U.S. Department of Commerce & U.S. Department of the Navy, 2001). The operational/environmental conditions were also dissimilar (e.g., no constrictive channel and a limited number of ships and sonar transmissions). NMFS noted that environmental conditions were favorable for a shift from up welling to down welling conditions, which could have contributed to the event. However, other severe storm conditions existed in the days surrounding the strandings and the impact of these weather conditions on at-sea conditions is unknown. No harmful algal blooms were noted along the coastline.

Conclusions: All of the species involved in this stranding event are known to occasionally strand in this region. Although the cause of the stranding could not be determined, several whales had preexisting conditions that could have contributed to stranding. Cause of death for many of the whales was likely due to the physiological stresses associated with being stranded. A consistent suite of injuries across species, which was consistent with prior strandings where sonar exposure is expected to be a causative mechanism, was not observed.

NMFS was unable to determine any causative role that sonar may have played in the stranding event. The acoustic modeling performed was hampered by uncertainty regarding the location of the animals at the time of sonar transmissions. However, given the distance of the sonar use from the stranding location, the response of the animals following the cessation of transmissions would imply a flight response that persisted for many hours after the sound source was turned off (the system was passive). In contrast, the presence of a severe weather event passing through North Carolina during January 13 and 14 is a likely contributing factor to the North Carolina unusual mortality event of January 15.

4.6 San Diego, October 2015

Description: On October 21, 2015 two dead bottlenose dolphins were reported within one mile of each other in Coronado and Imperial Beach, and a third bottlenose dolphin was reported in Coronado which was in advanced stages of decomposition on October 31, 2015. All three dolphins were determined to be from the coastal stock which is found within 500 m of the coast. Navy ships reported the use of mid-frequency active sonar for brief periods of time, totaling 1.6 hours, on October 19 and 20. The closest Navy ship was about 6 NM (~11,100 m) from the stranding location (Danil et al., 2016).

Findings: None of the dolphins were emaciated, but showed varying signs of decomposition. Imaging and pathology findings varied between dolphins. Consistent findings between the dolphins included hemoabdomen (blood in the abdomen) and subcutaneous hemorrhage in the head region. The Navy reported that the sonar used was at a low duty cycle (one ping every 50–60 seconds), and that the ship's average speed was 10–14 knots (Danil et al., 2016).

Conclusions: Mandibular hemorrhage as seen in these dolphins has been reported in animals subject to peracute underwater entrapment and in beaked whale strandings associated with mid-frequency active sonar. However, the range to injury for this sonar and this species is about 10 m. Due to the speed of the ships, the duty cycle, and the speed of the dolphins, the dolphins would not be within the range to injury for more than a few seconds. In addition, the habitat for this stock of bottlenose dolphin is over 5 NM from the ship's nearest location. The Navy is confident that the sonar used prior to these strandings could not have caused the injuries reported.

5 CONCLUSIONS

Marine mammal strandings have been a historic and ongoing occurrence attributed to a variety of causes, both natural and anthropogenic. Over the last 50 years, increased awareness and reporting has led to more information about species affected and raised concerns about anthropogenic sources of stranding. While there have been limited numbers marine mammal mortalities potentially associated with U.S. Navy activities, the root causes are not clear in most cases.

Future analyses and potential mitigations related to the impact of mid-frequency active sonar on marine mammals should be considered in context with other stressors on marine mammal populations. Worldwide there have been about 50 known strandings resulting in about 40 deaths among cetaceans, consisting mostly of beaked whales, with a potential causal link to sonar (International Council for the Exploration of the Sea, 2005). The Navy continues to implement mitigation, report any findings of stranded marine mammals, and reports when large exercises involving sonar may be conducted (National Marine Fisheries Service, 2013a, 2013b). A constructive framework and continued research based on sound scientific principles is needed in order to minimize speculation of stranding causes and to further our understanding of the potential effects of Navy sonar on marine mammals (Barlow & Gisiner, 2006; Bradshaw et al., 2006; Cox et al., 2006; Southall et al., 2007). Results from recently completed research (Antunes et al., 2014; Helble et al., 2016b; Manzano-Roth et al., 2016; Martin et al., 2015a; McCarthy et al., 2011; Miller et al., 2014; Sivle et al., 2015; Tyack et al., 2011; Visser et al., 2016) have suggested that investigations concerned with general behavioral responses to sonar (not necessarily investigating the causes of strandings), may be much more significant to our understanding of the potential impacts of sonar than investigations into the occasional and rare strandings of marine mammals that may have been associated with sonar use.

6 References

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