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Beaked Whale Strandings and Naval Exercises

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Abstract

Mass strandings of beaked whales (family Ziphiidae) have been reported in the scientific literature since 1874. Several recent mass strandings of beaked whales have been reported to coincide with naval active sonar exercises. To obtain the broadest assessment of surface ship naval active sonar operations coinciding with beaked whale mass strandings, a list of global naval training and anti-submarine warfare exercises was compiled from openly available sources and compared by location and time with historic stranding records. This list includes activities of navies of other nations but emphasizes recent U.S. activities because of what is available in publicly accessible sources. Of 136 beaked whale mass stranding events reported from 1874 to 2004, 126 occurred between 1950 and 2004, after the introduction and implementation of modern, high-power mid-frequency active sonar (MFAS). Of these 126 reports, only two reported details on the use, timing, and location of sonar in relation to mass strandings. Ten other mass strandings coincided in space and time with naval exercises that may have included MFAS. An additional 27 mass stranding events occurred near a naval base or ship but with no direct evidence of sonar use. The remaining 87 mass strandings have no evidence for a link with any naval activity. Six of these 87 cases have evidence for a cause unrelated to active sonar. The large number of global naval activities annually with potential MFAS usage in comparison to the relative rarity of mass stranding events suggests that most MFAS operations take place with no reported stranding events and that for an MFAS operation to cause a mass stranding of beaked whales, a confluence of several risk factors is probably required. Identification of these risk factors will help in the development of measures to reduce the risk of sonar-related strandings.

Key Words: stranding event, mass stranding event, mid-frequency active sonar, MFAS, beaked whale, Navy sonar, Ziphiidae

Introduction

Several articles have suggested that naval surface ship's use of mid-frequency active sonar (MFAS) cause mass strandings of beaked whales (family Ziphiidae) (Frantzis, 1998, 2004; Evans & England, 2001; Martín Martel, 2002; Brownell et al., 2004; Freitas, 2004; Martín et al., 2004).

Although different navies have different definitions for MFAS, *Jane's Underwater Warfare Systems* (Watter, 2004) defines these active sonars as operating in the frequency range of 3 to 14 kHz. Other reports (Evans & England, 2001) note MFAS center frequencies for two tactical sonars to be between 2.6 and 8.2 kHz. Most are hull-mounted or towed variable-depth sonars on anti-submarine warfare (ASW) naval surface vessels (e.g., frigates and destroyers). Individual system descriptions are available in *U.S Naval Weapons* (Friedman, 1988) and *The Naval Institute Guide to World Naval Weapons Systems* (Friedman, 1989). Approximately 632 surface ships from 46 countries are currently fitted with a hull-mounted sonar system operating in the medium-frequency range (Watter, 2004).

Recently released U.S. Department of the Navy Environmental Impact Statements (EIS)/ Overseas Environmental Impact Statements (OEIS) provide detailed descriptions of the types and amounts of naval training that occur on the U.S. Navy's Range Complexes. Data from several major range complex EIS/OEIS documents available online have been pooled to provide an estimate of active sonar usage per year by U.S. Navy surface ship (AN/SQS-53C and AN/SQS-56) sonars, submarine sonars, and helicopter dipping active sonars. The environmental documents for the range complexes—Atlantic Fleet Active Sonar Training Range (AFAST) (U.S. Department of the Navy [U.S. DoN], 2008a), Hawaii Range Complex (HRC) (U.S. DoN, 2008b), Northwest Training Range Complex (NWTRC) (U.S. DoN, 2008c), Southern California Range Complex (SoCal) (U.S. DoN, 2008d), and the Marianas Range Complex (U.S. DoN, 2009)—estimate 5,969 ping-hours annually for AN/SQS-53C and 1,437 ping-hours for AN/SQS-56 sonars. An additional 825 ping-hours are listed for submarine BQQ-10 and -15 sonars. Helicopter-deployed dipping active sonar usage is expressed in dips except in one of the documents that lists 160 ping-hours. It was not possible to determine what fraction of total annual U.S or world. MFAS sonar use is represented by these five major test and training range environmental risk assessments. Sonar use by other navies, joint international exercises, and training or engineering trials by vessels outside the ranges will also add an undetermined amount of sonar sound to the world's oceans each year. Whether the additional sonar use is equal to, greater than, or less than the documented U.S. Navy sonar use on its five major test and training ranges is, however, at present unknown.

A smaller number of MFAS systems may also be undergoing testing and development at any given time. A new generation of surface ship low-frequency active sonars (LFAS), operating at 2 kHz or lower, are currently in various stages of technical development and deployment (Pengelley & Scott, 2004). Table IX of *Jane's Underwater Warfare Systems* (Watter, 2004) summarizes all surface ship sonars (active and passive) operating very low-frequency (below 1 kHz), low-frequency (below 3 kHz), medium-frequency (3 to 14 kHz) and high-frequency (above 14 kHz) bands.

It is nearly as difficult to estimate the number of mass strandings of beaked whales as amount of sonar usage. The true number of mass stranding events must be greater than reported due to unreported events plus variations in the fidelity of historical records from differences in human coastal use, survey efforts, and reporting effort. To provide a database as comprehensive as possible, beaked whale stranding reports were collected from all available sources, including scientific journals, stranding network records, and newspaper reports. The analysis presented here follows the convention of Geraci & Lounsbury (1993) which defined a mass stranding as a case involving two or more animals, excluding mother-calf pairs, unless a third whale strands as well. The definition of *mass stranding* used in this analysis does not require that two or more animals died, just that two or more were reported stranded. Whales usually mass strand in the same place and simultaneously; however, recent reports of beaked whale strandings associated with naval exercises (Simmonds & Lopez-Jurado, 1991; Frantzis, 1998, 2004; Evans & England, 2001; Martín Martel, 2002; Freitas, 2004; Martín et al., 2004) have suggested that they may occur over more than 1 d and along many km of coastline. Frantzis (1998) defined an "atypical" mass stranding as a stranding event with an unusually large geographical and time course. In order to uncover these atypical mass strandings within the full stranding database, strandings were categorized as part of a mass stranding event if two or more animals were reported stranded within a 6-d period and 74 km (40 nmi) spread along the coast.

It is difficult to estimate naval MFAS use worldwide over any 1 y. At any given time, a significant fraction of ships with active sonars are in port or otherwise employed with the sonar not in use. Even for activities which involve active sonar use, the amount of time the sonar is in use may vary from minutes to a few hours or days during an exercise spanning many days or weeks (Evans & England, 2001). To obtain a measure of reported use of MFAS in given years, openly available sources were reviewed, particularly U.S. Navy and NATO press releases, as well as public Internet news sources. These sources provided a list of approximately 121 major exercises over a 13-y period (1992 to 2004). Exercises comprised one or more ships with MFAS systems or involved a multi-ship, multinational exercise in which specific ships were not identified, during which MFAS use for the ASW component of the exercise was assumed. This list of naval training and exercises is biased toward U.S. activities and recent years since information on U.S. Navy ships was most readily available from publicly accessible sources. It also includes information from navies of other nations. Available information did not always indicate whether MFAS was actually used during these exercises. The U.S. Department of the Navy (U.S. DoN) (2008a, 2008b, 2008c, 2008d, 2009) also maintains at-sea operational training ranges where active sonar may be used. Some reports (e.g., Brownell et al., 2004) assumed that strandings near ranges involved active sonar exposure, but proximity to a range provides weaker evidence for coincidence with active sonar use than proximity to an ongoing exercise.

As with the stranding data, public reports on naval activities may also be affected by uneven reporting effort, varying levels of completeness, and inaccuracies in the information provided. Often, only general descriptions of the geographic regions where the exercise occurred were given.

Despite these limitations, a "best-effort" attempt was made to provide the most comprehensive list possible of documented naval activities to analyze coincidence in time and place with beaked whale mass strandings. Both the data on strandings and on naval activities were obtained from publicly available and independently verifiable sources and are subject to similar potential flaws.

The only marine mammal stranding known to date to have coincided with use of an LFAS system occurred during a test that used both low-frequency and mid-frequency active sources concurrently (D'Amico & Verboom, 1998). This test was conducted by the NATO Undersea Research Centre (NURC), formerly known as SACLANT Undersea Research Centre, a NATO oceanographic research center in La Spezia, Italy. In May 1996, NURC conducted a Shallow Water Acoustic Classification (SWAC) research trial in the Kiparissiakos Gulf in western Greece, using the Towed Vertically Directive Source (TVDS). The TVDS had two arrays of sound sources tuned to low and mid-frequencies (centered at 600 Hz and 3 kHz with maximum source levels of 228 and 226 dB re 1μPa at 1 m, respectively). An atypical mass stranding of 14 Cuvier's beaked whales (*Ziphius cavirostris*) spread along 38 km of coastline of the Kiparissiakos Gulf (Frantzis, 1998) occurred starting within a few hours of the onset of sonar transmissions and continuing over 2 d of transmissions (D'Amico & Verboom, 1998). From 1994 to 1996, NURC conducted four other sea trials using the TVDS (D'Amico & Verboom, 1998). Prior to the use of the TVDS source, D'Amico & Verboom report six active acoustic trials conducted by NURC from 1981 to 1992. The acoustic sources used in those trials had source levels that were less than 215 dB re 1μPa at 1 m. D'Amico & Verboom stated that none of these acoustic trials coincided with reported mass strandings of beaked whales.

The combined data on strandings and naval activities allow observations about the number and fraction of reported beaked whale mass strandings that occurred at or near the time and place of reported naval activities that may have included MFAS. These data also permitted rough estimates of the number of beaked whale mass strandings reported relative to the number of reported naval activities that may employ MFAS. It must be noted that not all animals adversely impacted can be counted on to strand where they can be detected from shore, so even for areas with a good stranding network, lack of evidence for strandings cannot be interpreted as proof of no risk. For those few mass strandings of beaked whales for which a corresponding naval activity is well-documented, some common features of the underwater sound field during those specific activities have been identified (D'Spain et al., 2006). These associations must be viewed as tentative because of limited sample size, but they offer insights about the circumstances of species involved, physical environment, and active sonar use that are most definitively associated with strandings. Hypotheses derived from these observations can help determine efficacious approaches for managing potential risks from future operations of MFAS.

Materials and Methods

Strandings

Beaked whale stranding data were acquired from a variety of sources. The majority of the stranding reports were based on records found in the published literature. In some cases, original published reports or copies of original data records were obtained and reviewed to verify stranding details. Based on a review of the literature, some stranding records were eliminated from further analysis if found to involve direct human intervention such as by-catch, drive-fisheries, a ship strike, etc., or were found not to be a mass stranding but, rather, a collection of skeletal elements and long-term beach casts for which the observer could not determine if a multiple stranding had occurred within 6 d.

In recent years, regional stranding networks have been organized formally or informally in many parts of the world, providing additional sources of data on strandings.

From the above data sources and additional literature reports of beaked whale sightings, a beaked whale global database consisting of several thousand sighting and stranding records was developed (D'Amico et al., 2003; MacLeod, 2004; MacLeod & Mitchell, 2006). The stranding records in this database were reviewed to determine which records constituted a mass stranding event. An extensive list of strandings (1803 to 2003) in the Mediterranean Sea, gleaned from published and unpublished reports from national stranding networks and personal communications with local marine mammal researchers, was also employed (Podestá et al., 2006), as was stranding data collated by the Australian Department of Environment and Heritage (1790 to 1994) and provided by the Australian Defense Science and Technology Organization (DSTO). The Cetacean Distributional Database, available from the Marine Mammal Program, Smithsonian Institution, was used both as a resource for original source citations for some of the strandings cited in this study and a source of stranding reports (1876 to 2000). Lastly, some data were collected by searches for recent, single reports; marine mammal-related Internet sites; and newspaper accounts.

For this study, single animal strandings were categorized as part of a mass stranding event if two or more animals were reported stranded within a 6-d period and 74 km (40 nmi) spread along the coast. This definition was based on temporal and geospatial (latitude, longitude) groupings. It is similar to the atypical stranding as defined by Frantzis (1998) but is more inclusive, allowing a greater spread in time and space. Using these broader criteria for temporal-spatial distribution for a beaked whale stranding database increases the number of mass stranding events reported compared to previous reviews (Taylor et al., 2004; International Council for Exploration of the Seas [ICES], 2005). Mass strandings were determined only by the reported date when animals were found on the beach, which is not necessarily the time of death. Further, strandings that spanned a length of coastline greater than 74 km but were reported as a single event in the literature, such as the Bahamas strandings in 2000 (Balcomb & Claridge, 2001; Evans & England, 2001) and the Canary Islands strandings in 1988, 2002, and 2004 (Vonk & Martín Martel, 1989; Martín Martel, 2002; Fernández, 2004; Fernandez et al., 2004, 2005; Martín et al., 2004; Espinosa et al., 2005), for this paper were considered as single mass stranding events at each generally reported location.

Mass stranding events were grouped by ocean areas. The geospatial location was given either by the original reference or, if the original reference listed a city or place name only, this site was georeferenced as the nearest coastal latitude and longitude. Linear distances between stranded animals were calculated to determine if single or multiple strandings met the 74-km criteria for data through the end of 2004. While this list is undoubtedly not exhaustive, it is the most complete georeferenced beaked whale mass strandings data to date and contains a number of records not previously noted in earlier reviews.

Naval Exercises

A list of U.S., foreign, and joint naval exercises was compiled from unclassified sources; the majority were Web-based or otherwise publicly accessible. The primary official source from which five or more references were obtained are the following:

Official U.S. Navy, U.S. Government, and NATO Websites

- Allied Joint Force Command Naples: www.afsouth.nato.int
- Asia Pacific Defense Forum: http://forum.apan-info.net
- National Technical Information Center (NTIS): www.ntis.gov
- U.S. European Command: www.eucom.mil
- U.S. Navy website: www.navy.mil

The exercises obtained from the websites represent major multi-ship naval exercises that had an ASW focus and/or involved surface ships that have MFAS. It is not possible to ensure that the list is exhaustive nor whether most exercises included MFAS use because this information was not always available from publicly available sources. D'Amico & Verboom (1998) listed 11 active sonar exercises which have been included in this study.

Without specific information regarding the type of naval exercise that occurred; which, if any, active sonars were used; and/or the number and positions of ships that participated in the exercise, it is not possible to test for a direct relationship between use of MFAS and a beaked whale mass stranding event. A ranking system for the quantity and quality of available data for each event was developed as a rough metric of the relative level of confidence offered by the data for inferences about the possible role of MFAS in a given stranding event, ranging from "1" (most robust) to "5" (least robust). Ranking criteria are as follows:

1. Detailed data on timing and location of the stranding and the active transmissions from the naval activity AND no evidence for an alternative cause of strandings
2. Incomplete knowledge of timing and location of the stranding or the naval activity (including information on active sonar usage) AND no evidence for an alternative cause of strandings
3. No knowledge whether active sonars were used BUT the stranding was close in space and time to a naval facility or naval vessel near which active sonar use is plausible, though not documented
4. No knowledge if active sonars were in use in the area
5. No evidence of active sonar use BUT evidence for an alternate cause of stranding

Results

The "Appendix" provides a list of all the mass stranding events used for this study, the references used to obtain the stranding information, and their associated ranking. One hundred thirty-six beaked whale (family Ziphiidae) mass stranding events comprising 539 animals were reported worldwide in the 131 y of available records (1874 to 2004). Ten events (52 animals) were reported prior to 1950. Two of the pre-1950 events (31 animals) consisted of a single *Mesoplodon* species (*M.* grayi) in New Zealand, two events (four animals) consisted of *M. layardii* in Australia, and the remaining six events (17 animals) consisted of either *Hyperoodon ampullatus* or *Berardius bairdii*. The earliest documented beaked whale mass stranding involved 28 *M. grayi* (Haast, 1876), which stranded in 1874 on the Chatham Islands of New Zealand; this single event accounts for the majority of individuals involved in events prior to 1950. These events predate the development of modern surface ship MFAS systems operating at the frequencies and amplitudes used today. No single or mixed species mass stranding event containing *Z. cavirostris* had been documented prior to 1950. The first recorded mass stranding event of *Z. cavirostris* consisted of two animals in March 1960 off the southeast coast of Japan (National Science Museum, Tokyo, 2009), after the introduction of the first medium-frequency sonars, the AN/SQS-4 series, entered fleet service in 1954 (Friedman, 1989; D'Amico & Pittenger, this issue).

Of the 126 beaked whale mass strandings (487 animals) over the 55-y period from 1950 to 2004, 118 were single species events and eight were mixed species events containing *Z. cavirostris* with at least one other ziphiid (Table 1). Of the 118 single species events, 104 events (368 animals) were single species mass strandings of the genera *Ziphius* or *Mesoplodon*. Out of all single species mass stranding events, the largest percentage of events, 45.8% (54 events, 216 animals), involved the species *Z. cavirostris*. Events containing animals of the genus *Mesoplodon* represent 42.4% (50 events, 152 animals). Within the genus *Mesoplodon*, *M. stejnegeri* and *M. grayi* had the largest percentage of the total single species mass stranding events—9.3% (11 events, 28 animals) and 8.5% (10 events, 47 animals), respectively. No mass stranding events were recorded for seven of the 14 *Mesoplodon* species (*M. bowdoini*, *M. carlshubbi*, *M. ginkgodens*, *M. mirus*, *M. perrini*, *M. peruvianus*, and *M. traversii*) and *Indopacetus pacificus*. Two of these species (*M. perrini* and *M. traversii*) have been designated as distinct species only recently (MacLeod et al., 2006). Mass strandings of species not from the genera *Mesoplodon* or *Ziphius* (*B. arnuxii*, *B. bairdii*, *H. ampullatus*, *H. planifrons*, and *Tasmacetus shepherdii*) represent 10.2% (12 events, 39 animals) of the total; *H. ampullatus* comprised the largest single species percentage in this category at 5.1% (6 events, 13 animals). The remaining two events (four animals) were Ziphiidae, but they were not identified to genera. Stranding events reported as associated with naval activities have all involved *Z. cavirostris* alone or in mixed strandings comprising *Z. cavirostris* and *Mesoplodon* spp. or *H. ampullatus*.

The data show eight mixed species stranding events from 1950 to 2004 (Table 1), all of which occurred after 1961. All involved *Z. cavirostris* and at least one other beaked whale species. The first recorded mixed species stranding event included *Z. cavirostris* and *M. densirostris* on Midway Island, Hawaii, in 1961 (Galbreath, 1963). Two events, in the Canary Islands in 1988 (Vonk & Martín Martel, 1989) and in the Bahamas in 2000 (Balcomb & Claridge, 2001; Evans & England, 2001), were reported to include species other than beaked whales (*Kogia breviceps* and *Balaenoptera acutorostrata*, respectively). Six mixed species stranding events contained either *M. europaeus* or *M. densirostris*, or *H. ampullatus*.

The mass stranding events occurring between 1950 and 2004 were summarized by ocean region and are shown in Figure 1. Of the 54 single species mass stranding events of *Z. cavirostris*, nearly half of these (25 events, 106 animals), or 21.2% of the total single species mass stranding events (19.8% of total mass stranding events), were

Table 1. Multi-species beaked whale stranding events from 1950 to 2004 (includes non-beaked whale species): *Hyperoodon ampullatus* (Ha), *Balaenoptera acutorostrata* (Ba), *Kogia breviceps* (Kb), *Mesoplodon densirostris* (Md), *M. europaeus* (Me), *Ziphius cavirostris* (Zc), Ziphiidae spp. (Zsp), and *Mesoplodon* spp. (Msp)

Year	Location	Species mix	Total # animals	Total # Zc	Total # Msp	Total # other Zsp	Total # other species
1961	Midway, U.S.	Zc, Md	3	1	2		
1969	Scotland, UK	Zc, Ha	2	1		1	
1985	Canary Islands, Spain	Zc, Me	13	12	1		
1986	Canary Islands, Spain	Zc, Me	5	4	1		
1988	Canary Islands, Spain	Zc, Ha, Kb	6	3		1	2
1989	Canary Islands, Spain	Zc, Me, Md	20	15	5		
2000	Bahamas	Zc, Md, Zsp, Ba, Me[a]	17	9	4	2	2
2002	Canary Islands, Spain	Zc, Me, Md	14	10	4		
			80	55	17	4	4

[a]Report of Me as part of this event was listed in Balcomb & Claridge (2001) and not included in Evans & England (2001). *Stenella frontalis* was not considered part of the mass stranding event in Evans & England (2001) and, thus, was not included.

reported in the Mediterranean Sea (Podestá et al., 2006). The dominance of *Z. cavirostris* in the stranding databases may be due to the predominance of the Mediterranean region in the stranding records since this is the only beaked whale species (*Z. cavirostris*) regularly seen in those waters (Notarbartolo & Demma, 1994), In addition, the region has a relatively high human population density and, compared to many other areas, relatively long-term, well-documented records on marine mammal strandings (Podestá et al., 2006).

The western north Pacific accounted for 19.8% of the total mass stranding events (25 events, 82 animals). The majority of these events occurred around Japan (Ishikawa, 1994; Brownell et al., 2004; National Science Museum, Tokyo, 2009). The western south Pacific (including Australia and New Zealand) (23 events, 80 animals), and the eastern North Atlantic (including the United Kingdom and the Canary Islands, Spain) (21 events, 96 animals) account for 18.3% and 16.7% of the total events, respectively.

At least one event containing *Z. cavirostris* occurred in each ocean area outlined in Figure 1 except in the southern hemisphere regions (eastern and western South Atlantic and Pacific, except Galápagos, Ecuador). This may reflect the distribution of beaked whales worldwide; however, given the high density estimates of beaked whales in the Antarctic/Southern oceans (Barlow et al., 2006), it is more likely to at least partly reflect an artifact of the lower probability of detection and reporting of strandings due to low human population densities in much of the southern hemisphere compared to the northern hemisphere.

No beaked whale mass strandings were reported in published reviews of strandings for New Caledonia (Borsa, 2006); the U.S. Washington-Oregon coast (Norman et al., 2004); the Hawaiian Islands (Mazzuca et al., 1999; Maldini et al., 2005); the west coast of Canada (Willis & Baird, 1998); and Sable Island, Nova Scotia (Lucas & Hooker, 2000). All are regions with well-established reporting since 1877, 1930, 1937, 1970, and 1970, respectively.

Twenty-seven events were designated mass strandings even though not all the animals died. For five events, animals entered a harbor or shallow water area but survived by returning to deep water spontaneously or with assistance. For the remaining 22 events, not all the animals died; some animals died, and some were assisted to deeper water or swam away unassisted.

The global map in Figure 1 shows that mass stranding events are more commonly reported in some regions of the world than others, at least on a very coarse scale. Eight mass stranding focal areas in which six or more mass stranding events have occurred within 370 linear km (200 nmi) of coastline have been defined (highlighted in gray in Figure 1; listed in Table 2). Five of the eight mixed species events occur in a single focal area: the eastern Canary Islands (Vonk & Martín Martel, 1989; Martín Martel, 2002; Fernández,

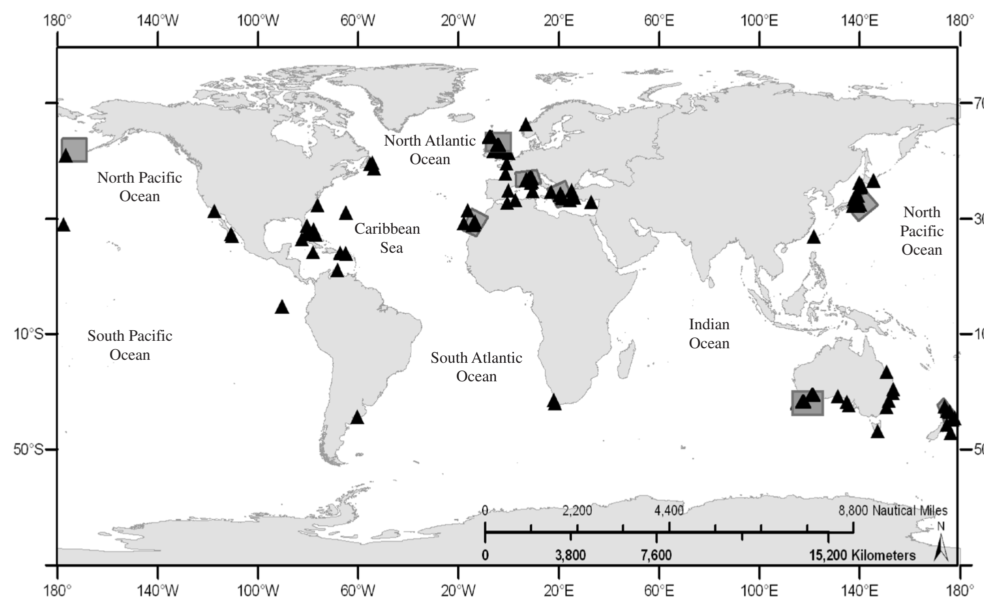

Figure 1. Geographic plot of global beaked whale mass strandings for all Ziphiidae from 1950 to 2004 (only the northernmost position of each animal per mass stranding event is plotted); eight mass stranding focal areas are highlighted in gray.

2004; Fernández et al., 2004, 2005; Martín et al., 2004; Espinosa et al., 2005).

Figure 2 shows the number of beaked whales per mass stranding event from 1950 to 2004. Approximately half of the mass stranding events (48%, 120 animals) shown in Figure 2 contain only two animals. The vast majority (82%, 266 animals) of all ziphiid mass stranding events contain four or fewer animals. The remainder of the events consist of more than four animals. There are 23 strandings of greater than four Ziphiidae in the 55-y time period from 1950 to 2004, accounting for 18% of the total events (with 221 animals involved). By comparison, there were two events of more than four animals reported prior to 1950, which represented 20% of the total events (with 33 animals involved) between 1874 and 1949. Of these 23 events that occurred between 1950 and 2004, five involved more than one ziphiid species. Sixteen of these events occurred in six of the eight focal areas (Table 2).

Figure 3 shows the number of mass stranding events globally by year from 1950 to 2004.

Table 2. List of mass stranding focal areas for all Ziphiidae from 1950 to 2004

Focal area	Number stranding events	Number animals reported	Earliest date	Latest date	Number stranding events with > 4 Ziphiidae	Number strandings with multi-species
Greece (Eastern Ionian Sea)	7	36	1993	1997	2	0
SE France/NW Italy (Northern Ligurian Sea)	7	44	1961	1996	3	0
Northern United Kingdom	6	14	1950	1992	0	1
Spain, Canary Islands (Fuerteventura, Lanzarote)	7	63	1985	2004	4	5
United States (Adak Island, Alaska)	6	18	1975	1994	0	0
Japan (SE Honshu Island)	12	54	1960	1995	4	0
New Zealand (North Island)	7	34	1974	2004	2	0
Western Australia	6	19	1986	2003	1	0

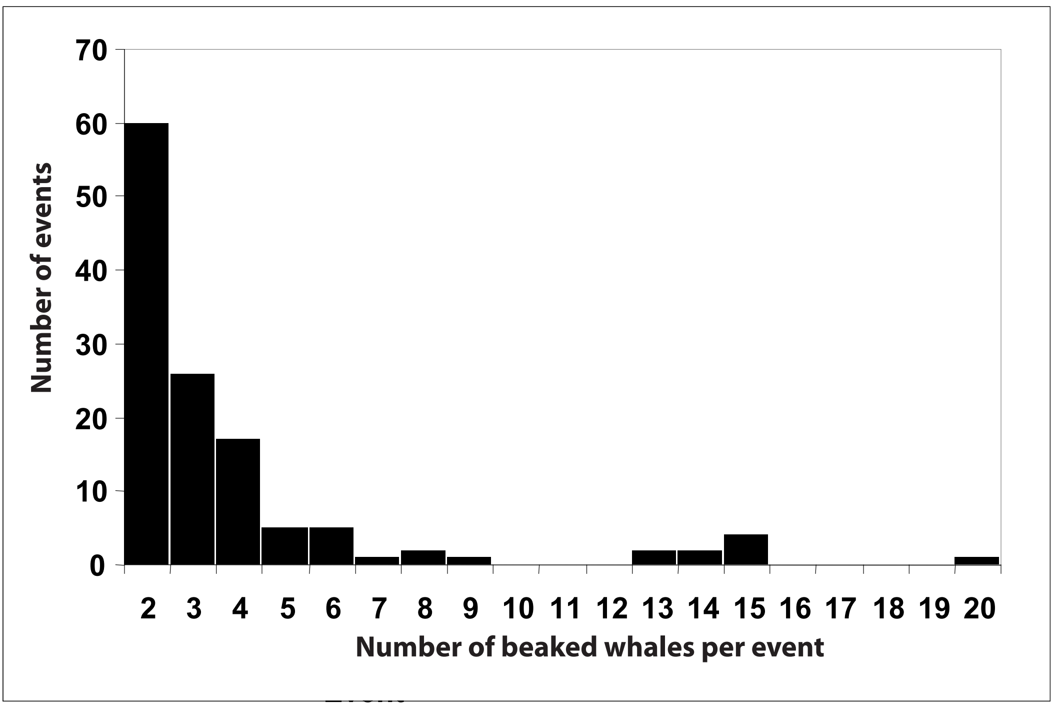

Figure 2. Distribution of number of cetaceans per recorded mass stranding event from 1950 to 2004 for all Ziphiidae

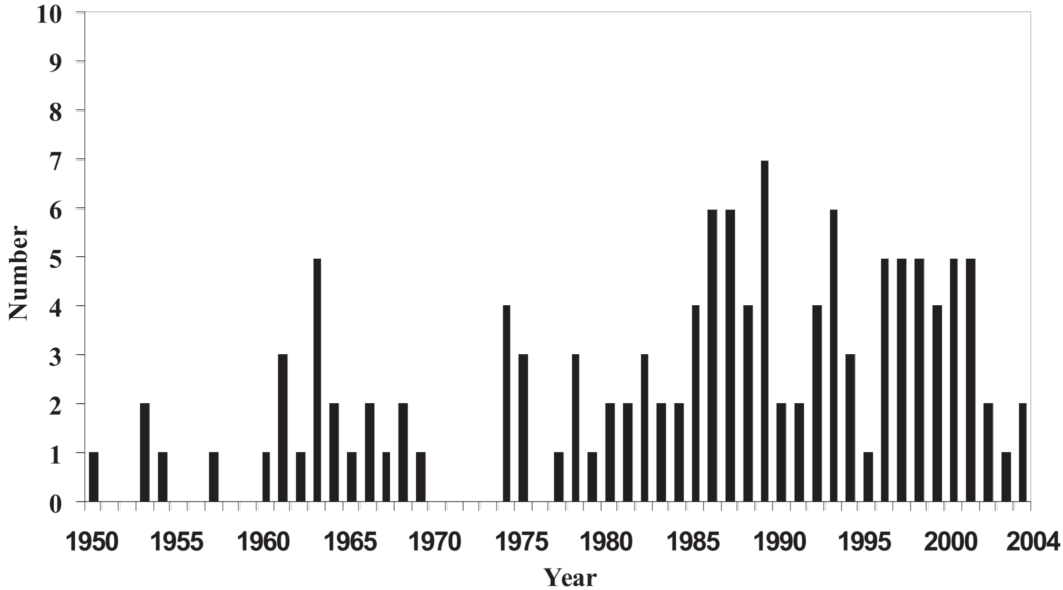

Figure 3. Number of recorded beaked whale mass stranding events by year from 1950 to 2004

Although there were years with limited or no mass strandings in the late 1960s to mid-1970s, in general, there was a mean of 2.3 reported mass stranding events per year with a mean of 8.9 animals per year. Looking at a narrower time interval of 20 y from 1985 to 2004, there was a mean of 4.0 reported mass stranding events per year with a mean of 15.2 animals per year. For the 5-y period for which the majority of information on naval operations is available (2000 to 2004), there was a mean of 3.0 reported mass stranding events per year with a mean of 13.0 animals per year, globally.

Beaked whales are known to be deep divers. Recent tag data collected on three beaked whale species, *H. ampullatus*, *Z. cavirostris*, and *M. densirostris* (Hooker & Baird, 1999; Johnson et al., 2004; Baird et al., 2005; Tyack et al., 2006), recorded deep foraging dives with maximum depths ranging from approximately 700 m to greater than 1,800 m. Based on these dive data, a representative water depth of 1,000 m was used as an estimation for the location of the beaked whale habitat. Figure 4 shows a histogram of the minimum distance from the beaked whale mass stranding event to the 1,000-m depth contour. The 1,000-m depth contour was derived from the ETOPO2 gridded bathymetry available from the National Oceanic and Atmospheric Administration (NOAA) (2001). Figure 4 indicates that 79% of all beaked whale mass stranding events recorded globally during the 55-y period from 1950 to 2004 occurred less than 80 km from the 1,000-m depth contour. Using tools available in ESRI *ArcInfo* (geospatial analysis software) and low-resolution shoreline data, it was estimated that for 62.7% of the globe, the 1,000-m depth contour was less than 80 km to the coastline. This suggests that beaked whale mass strandings occur in geographic regions where the 1,000-m depth contour is closer to shore.

Table 3 contains the total number of mass stranding events and the corresponding number

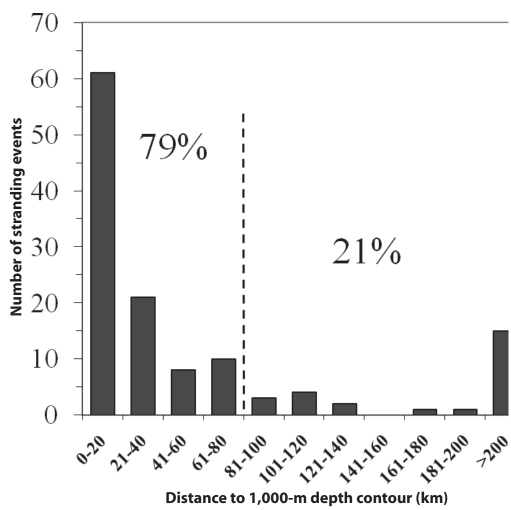

Figure 4. Histogram showing number of beaked whale mass stranding events for all Ziphiidae compared to distance to 1,000-m depth contour; the 79% and 21% values represent cumulative percent of events less than 80 km (43 nmi) and greater than 80 km.

Table 3. Summary of recorded beaked whale mass stranding events from 1950 to 2004 sorted by rank for all Ziphiidae based on amount and quality of available data ranging from "1" (most robust) to "5" (least robust)

Rank	Number stranding events	% of total events	Number animals reported	% of total animals
1	2	1.6%	29	6.0%
2	10	7.9%	76	15.6%
3	27	21.4%	125	25.7%
4	81	64.3%	239	49.1%
5	6	4.8%	18	3.7%
Total	126		487	

of animals for each data rank category, with the rank of "1" indicating the highest quality and totality of evidence as described in the "Materials and Methods" section. The Bahamas 2000 and the Greece 1996 mass stranding events were the only mass stranding events assigned the rank of "1" because detailed information were available on both the timing and location of the stranding and the concurrent nearby naval activity, including verification of active sonar usage, with no evidence for an alternative cause of stranding (D'Amico & Verboom, 1998; Frantzis, 1998; Evans & England, 2001; Ketten et al., 2004; Ketten, 2005). The findings for the Bahamas, presented in Evans & England (2001), stated "the investigation team concludes that tactical mid-range frequency sonars aboard U.S. Navy ships that were in use during the sonar exercise in question were the most plausible source of this acoustic or impulse trauma" (p. ii). The Greek stranding occurred during the same time period as a NURC Shallow Water Acoustic Classification (SWAC) research trial in the Kiparissiakos Gulf in western Greece in May 1996 (Frantzis, 1998). Detailed discussion of the ship's movements and active sonar transmissions can be found in D'Amico & Verboom (1998).

Ten events were assigned the rank of "2," indicating weaker evidence than for "1," as there was incomplete knowledge of timing and location of the stranding or the naval activity and there was no evidence for an alternative cause of stranding. Three of these events (Madeira, Portugal, 2000; and Canary Islands, Spain, 2002 and 2004) coincided with naval exercises. Detailed necropsies of stranded cetaceans were available, but detailed ship-tracks or data on the precise time, locations, or signals of any active sonar use were not available. Necropsy results from the animals stranded in Madeira in May 2000 are detailed in Freitas (2004) and Ketten (2005). This stranding occurred during the NATO exercise LINKED SEAS 2000 in Porto Santo, Portugal, which took place from 11 to 14 May 2000 (Anon., 2000; Freitas, 2004). The Canary Island stranding of 2002 occurred during the NATO NEOTAPON exercise (Martín Martel, 2002; Martín et al., 2004) conducted in September 2002. Necropsy results can be found in Fernández (2004) and Fernández et al. (2005). The Canary Island stranding of 2004 occurred the week following a NATO exercise MEDSHARK/Majestic Eagle '04 off the Atlantic coast of Morocco (Anon., 2004a; Fernández et al., 2004; Omo, 2004; Espinosa et al., 2005). Necropsy results for three out of the four stranded animals from this stranding event can be found in Fernández et al. (2004) and Espinosa et al. (2005). Detailed data on ship-tracks or the location and timing of active sonar transmissions are not available for the LINKED SEAS 2000, NEOTAPON 2002, and the MEDSHARK/Majestic Eagle 2004 exercises.

For the other seven of the ten events ranked "2," a naval exercise or the presence of a ship outfitted with MFAS spatially and temporally coincided with the stranding event, but there was limited information on the ships' movements or the type of active sonar transmissions that occurred (if any). There were no detailed necropsy results. Three of these seven events occurred in the Canary Islands. The naval exercises concurrent with the three Canary Island strandings have been identified as FLOTA '88, CANAREX '89, and SINKES '91 (Simmonds & Lopez-Jurado, 1991; Martín Martel, 2002; Martín et al., 2004), corresponding to the November 1988, October 1989, and December 1991 mass stranding events, respectively. The remaining four events occurred in the Mediterranean Sea. Two occurred in western Greece over a 4-d period in October 1997 (Drougas & Kommenou, 2001; Frantzis, 2004; Podestá et al., 2006) and were separated by approximately 111 km (60 nmi). These two stranding events occurred during the same time period as the NATO exercise DYNAMIC MIX '97 (Anon., 1997; Frantzis, 2004). The third occurred during the same time period as a SHAREM INVITEX exercise in the Gulf of Valencia, Spain, in February 1996 (Blanco & Raga, 1997, 2000; Anon., 2009). The seventh event occurred in November 1963 off the northwest coast of Italy. An anonymous source (Anon., 1963a) identified the U.S. Gearing class frigate *William C. Lawe* as present in the area, while Littardi et al. (2004) identified the U.K. Rothesay-class frigate *Lowestoft* as present in the area. The U.S. Department of the Navy (2006) reported that the *William C. Lawe* (DD-763) was retrofitted during the Fleet Rehabilitation and Modernization (FRAM) program in which the U.S. Navy modernized its Gearing class destroyers with hull-mounted AN/SQS-23 sonars and was deployed in the Mediterranean Sea from August to December 1963 (Hackman, 1984; Friedman, 1988, 1989; Cote, 2000; Watter, 2004).

Twenty-seven events were assigned a rank of "3," indicating that no specific naval exercises were identified that would have coincided with the stranding. Three of these events have been linked anecdotally with the presence of a naval ship. Two of these three events happened near Genoa, Italy, in May 1963, and November 1966 and have been suggested to be associated with the presence of a Forrestal class aircraft carrier, the *Saratoga* (Anon., 1963b) and the *Independence* (Littardi et al., 2004), respectively. According to *Jane's* (Watter, 2004), these ships do not have active sonar, but they are often accompanied by MFAS-equipped ships. Therefore, these events have been categorized with rank "3." The third remaining event anecdotally linked to the presence of a naval ship occurred in the Canary Islands in 1985 and was listed as related to "naval maneuvers" with no additional details presented (Simmonds & Lopez-Jurado, 1991; Martín Martel, 2002; Martín et al., 2004).

Other rank "3" events were linked with possible naval active sonar use because the strandings occurred in proximity to a naval facility. Brownell et al. (2004) listed ten mass stranding events (*Z. cavirostris*) and one of *B. bairdii* (July 1987) that occurred on the central Pacific coast of Honshu (Sagami and Suruga Bay) near to the U.S. naval base at Yokosuka. All of these events with the exception of one event were ranked "3." The remaining event was ranked "5" as Ishikawa (1994) indicated interaction with fishing boats as a potential cause of stranding. One additional beaked whale (*Z. cavirostris*) stranding, which occurred in this area in November 1995 (National Science Museum, Tokyo, 2009) and was not listed in Brownell et al. (2004) but was included in this database, has also been ranked "3" because of the proximity to the Japan OPAREA (Operating Area) complex (U.S. DoN, 2005a). For seven other Category "3" events (six on Adak, Alaska, and one on Midway Island, Hawaii), the literature mentioned that animals were found by U.S. Naval personnel, suggesting that the stranding occurred near a U.S. Naval facility or operation (Galbreath, 1963; Walker & Hanson, 1999). Four other events occurred in the general vicinity of the Puerto Rico/St. Croix OPAREA complex in 1965, 1991, 1998, and 1999 (Erdman, 1970; Erdman et al., 1973; Mignucci-Giannoni & Rosario-Delestre, 1999; U.S. DoN, 2002a). Ketten (2005) examined three skulls from the 1999 stranding and determined the skulls to be normal with no evidence of blunt or direct trauma. The remaining two events occurred in 1963 and 1992 in the general proximity of the Southern California and Key West, Florida, OPAREAs, respectively (U.S. DoN, 2002b, 2005b). There were 81 mass stranding events or 64.3% of the total with no indication of any link to any naval activities or facilities. These were assigned the rank of "4."

Six events were ranked as "5" because additional data associated with the stranding suggested other causes were likely related to the stranding, including bullets in the carcasses, underwater explosions, hurricanes, ship strikes, and seismic surveys (Van Bree & Kristensen, 1974; Duguy, 1975; Viale, 1975; Ishikawa, 1994; Norman & Mead, 2001; Taylor et al., 2004).

Discussion

Since Frantzis (1998) reported a *Z. cavirostris* mass stranding in Kiparissiakos Bay, Greece, in 1996, there has been a growing awareness in the public and professional scientific communities that some mass strandings of beaked whales may be caused by modern MFAS on naval surface ships (Simmonds & Lopez-Jurado, 1991; Frantzis, 1998, 2004; Balcomb & Claridge, 2001; Evans et al., 2002; Martín Martel, 2002; Brownell et al., 2004; Fernández et al., 2004; Freitas, 2004; Ketten et al., 2004; Martín et al., 2004; Espinosa et al., 2005). The number of beaked whale mass strandings attributed to MFAS in some of these cited references and the rationale behind excluding or including specific events have not always been clearly defined.

This retrospective look at strandings from 1950 to 2004 suggested that 12 of 126 events (9.5%) can be considered to have coincided in space and time with naval activity that were likely to have included MFAS based on available data (ranking categories "1" and "2"). All of these events contained *Z. cavirostris*. Eight of these 12 events were single species strandings consisting of *Z. cavirostris* only, and the other four events were mixed species events containing *Z. cavirostris* and other species. Three out of the four mixed species events contained animals of the genus *Mesoplodon*, and the fourth contained an *H. ampullatus*. Of these 12 events, two were strongly associated in space and time with known MFAS use and ship activity (those of rank "1"), suggesting the use of MFAS could confidently be considered to be causally linked to the strandings. For the remaining ten events (those of rank "2"), there was evidence for a link with a specific naval exercise or a ship likely to involve active sonar use. For three of these ten events—Madeira (Portugal) in 2000 and Canary Islands (Spain) in 2002 and 2004—detailed necropsies were available (Martín Martel, 2002; Fernández, 2004; Freitas, 2004; Martín et al., 2004; Espinosa et al., 2005;

Fernández et al., 2005; Ketten, 2005). These rank "2" events are linked to MFAS activity solely due to a coincidence between a naval exercise or ship and the stranding location, with only limited information as to when and where MFAS was used.

For the 27 events assigned the rank of "3," several have been suggested to be related to naval activities (Anon., 1963b; Martín Martel, 2002; Brownell et al., 2004; Littardi et al., 2004; Martín et al., 2004). However, the evidence for a relationship between MFAS usage and stranding is not as strong in these cases as it is for strandings for which more data (ranks "1"and "2") are available. Based on available data on naval operations, for any rank "3" events, no naval operations that were spatially-temporally coincident have been identified. This reduces the strength of evidence or probability that these cases were MFAS-related strandings. For those rank "3" events that occurred in a remote place, such as Midway Island, Hawaii, and Adak, Alaska (Galbreath, 1963; Walker & Hanson, 1999), the animals may have been found by naval personnel because they constituted most or all of the residents in that area, not necessarily because the stranding was related to naval activities at sea. For those rank "3" events which suggest the presence of a naval vessel, such as the Italian May 1963 and November 1966 events (Anon., 1963b; Littardi et al., 2004) and the February 1985 Canary Island stranding event (Simmonds & Lopez-Jurado, 1991; Martín Martel, 2002; Martín et al., 2004), it is not known from available records if the ships present had any MFAS equipment.

Unfortunately, it has not yet been conclusively established what type of post-mortem finding would unequivocally indicate a MFAS-related stranding and mortality event. Tissues from the March 2000 Bahamas stranding, May 2000 Madeira stranding, and the September 2002 Canary Island strandings were collected and examined relatively soon after the death of the animals (Evans & England, 2001; Fernández, 2004; Freitas, 2004; Ketten et al., 2004; Ketten, 2005; Fernández et al., 2005). The expert evaluations of these post-mortem investigations raised the issue that certain observed traumas in these whales may have been caused by sound (Evans & England, 2001; Fernández, 2004; Freitas, 2004; Ketten et al., 2004; Martín et al., 2004; Fernández et al., 2005; Ketten, 2005), but the traumas reported for each incident are not completely consistent across all presumed MFAS-related strandings. Further, no exact causal mechanisms by which MFAS could lead to each or any of the reported trauma suites, how these would lead to initiating the stranding and death of whales, or why beaked whales seem to be particularly subject to MFAS impacts are known. Several hypotheses have been advanced, including resonance phenomena, direct acoustic impacts, hemorrhagic response related to coagulopathy and stress, and bubble formation linked to decompression syndrome (Evans & England, 2001; Houser et al., 2001; Evans et al., 2002; Jepson et al., 2003; Fernández, 2004; Cox et al., 2006). All hypotheses are under investigation, but to date, no clear, consistent suite of traumas has been found across the relatively few cases for which there are organized necropsy data and which thus can be considered emblematic of sonar exposure.

There are few estimates of the density or absolute abundance of beaked whales. Barlow et al. (2006) provide a discussion of available data for the North Pacific, North Atlantic, and Antarctic/Southern Oceans. This reference cites published density estimates that range from 0.4 to 4.4 whales per 1,000 km^2 for small beaked whales (*Z. cavirostris*, *Mesoplodon* spp., and *T. shepherdi*) and up to 68 whales per 1,000 km^2 for large beaked whales (*Berardius* spp., *Hyperoodon* spp., and *I. pacificus*).

At present, there are insufficient population data for any beaked whale species to support an analysis for baseline "normal" stranding rate vs a known offshore abundance. The stranding focal areas include nine out of 12 of the strandings ranked as "1" or "2." This association suggests that a high concentration of beaked whales relatively near shore, as indicated by the mass stranding data, is a clear risk factor for sonar-related strandings.

The comparison of reported beaked whale strandings before and after 1950 showed a clear difference in number. Only ten events were reported from 1874 to 1950, while 126 were reported between 1950 and 2004. Some of this difference could stem from increased observation and reporting effort after 1950, but there are qualitative differences as well. The pre-1950 strandings involved *M. grayi*, *M. layardii*, *H. ampullatus*, and *B. bairdii*. Even though *Z. cavirostris* occurs in areas off Europe and Japan where one might expect early stranding records, there are no records of mass strandings of *Ziphius* nor records of mixed species strandings before 1950. The one stranding of 28 *M. grayi* is the only stranding of greater than five beaked whales reported pre-1950 compared to 18 after 1950. Of these strandings of greater than five beaked whales from 1950 to 2004, 67% included *Z. cavirostris*. Two of the ten events reported prior to 1950 contained more than four animals and occurred prior to 1900 compared to 23 events containing more than four ziphiids between 1950 and 2004.

While there appears to be a slight increase in the trend of mass stranding events between the early 1960s and the late 1980s, this trend is less evident in the mid to late 1990s, with even fewer events per year in the last 3 y of the study period (2002 to 2004). It cannot be determined whether this apparent increase from the 1960s to the late 1980s represents an actual increase in strandings or whether it might be more representative of an increase in detection and reporting effort for marine mammal strandings.

Inconsistencies in the level of search and reporting effort over the periods covered violate the assumptions required for most statistical analyses. Therefore, this study was forced to rely on the available but imperfect evidence of coincidence in space and time between naval active sonar training and exercises and strandings. This was used as the best indicator of the potential magnitude of effects from MFAS usage on marine mammal strandings.

The amount of annual MFAS activity is also difficult to estimate. From the data on naval exercises during 2000 to 2004 for which general locations and dates were available (almost exclusively data on U.S. naval activities), it is estimated that approximately 11 major multinational, multi-ship exercises occur annually in the Mediterranean Sea, the North Atlantic Ocean, and the North Pacific Ocean combined. This suggests that a major exercise is likely to have an ASW component involving MFAS occurring, on average, about once a month in the Northern Hemisphere.

Considering that exercises from allied or non-allied nations, or single unit operations that may involve one or many of the 632 surface ships from 46 countries (only a portion of which may be operational) have not been included, the number of potential MFAS events each year is likely much higher than the figure of 11 major exercises per year in the Northern Hemisphere derived from open sources from 2000 to 2004. The location of these major exercises is only reported in general geographic terms; therefore, it is difficult to determine how many of these exercises occurred seaward of the 1,000-m depth contour (i.e., the approximation of beaked whale habitat used for assessing the beaked whale mass stranding data). Nevertheless, considering the approximate magnitude of MFAS usage in comparison to an average of 3.0 mass stranding events per year during this same time period suggests that the total beaked whale stranding events, whether the cause is known or not, are few relative to the number of sonar exercises in which MFAS is used worldwide.

Some consistent geographic and circumstantial consistencies have been identified among the 126 beaked whale mass stranding events:

- The majority of the mass stranding locations were less than 80 km from the 1,000-m depth contour, suggesting possible beaked whale habitat relatively close to shore.
- The majority (75%) of the documented stranding events that coincided in space and time with naval activity that may have included MFAS (ranked "1" and "2") occurred in a defined focal area (where six or more beaked whale mass stranding events have occurred) with half of these events containing greater than four Ziphiidae.

It is important to note that beaked whale mass stranding events, when considered globally, may be more numerous than previously thought and the number of these events that provide sufficient basis for confident association with naval activities is relatively small. However, there are a large number of cases for which there is insufficient information to test confidently for an association.

Identifying the conditions that separate the use of MFAS leading to strandings from the use of MFAS that do not result in strandings may help in the development of active sonar usage practices and mitigation measures that prevent adverse impact. Some conditions correlated with stranding events that may be viewed as probable risk factors have been reported. Further exploration of the phenomenon and attempts at quantification of possible contributing physical and biological conditions is clearly needed.

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Appendix. Beaked whale mass strandings

Beaked whale mass strandings with associated ranking; count does not include non-beaked whale species which were included in mixed species stranding (see Table 1). Species abbreviations: *Berardius arnuxii* (Bar), *B. bairdii* (Bb), *Hyperoodon ampullatus* (Ha), *H. planifrons* (Hp), *Mesoplodon bidens* (Mb), *M. densirostris* (Md), *M. europaeus* (Me), *M. grayi* (Mgr), *M. hectori* (Mh), *M. layardii* (Ml), *M. stejnegeri* (Ms), *Mesoplodon* spp. (Msp), *Tasmacetus shepherdii* (Ts), *Ziphius cavirostris* (Zc), and Ziphiidae spp. (Zsp); Non-beaked whales species: *Kogia breviceps* (Kb) and *Balaenoptera acutorostrata* (Ba).

Dates	Species	Number cetaceans stranded per event	Country	Rank	References
Aug 1874	Mgr	28	New Zealand	n/a	Haast, 1876[d]
29 Dec 1876	Mgr	3	New Zealand	n/a	Oliver, 1922
29 Aug 1891	Ha	5	France	n/a	Jouan, 1891; Bouvier, 1892; Brasil, 1909[d]
16 June 1903	Bb	2	US (AK)	n/a	True, 1910
20 Sept 1927	Ha	4	Scotland	n/a	Fraser, 1934[d]
3 Feb 1931	Ml	2	Australia	n/a	Hale, 1931
27 Aug 1931	Ha	2	UK	n/a	Berrow & Rogan, 1997
2 Feb 1939	Ml	2	Australia	n/a	Dixon, 1980[d]
30 July 1939	Ha	2	UK	n/a	Van Heel, 1962; Fraser, 1953
1 Aug 1948	Ha	2	UK	n/a	Fraser, 1974
5 Aug 1950	Zsp	2	UK	4	Fraser, 1974
27 July 1953	Ha	2	Canada (NF)	4	Mitchell & Kozicki, 1975[e]
16 Sept 1953	Ha	2	UK	4	Fraser, 1974
27 Sept 1954	Ha	3	Ireland	4	Fraser, 1974[d]
18 April 1957	Mb	2	Norway	4	Van Heel, 1962
3 March 1960	Zc	2	Japan	3	Nat. Sci. Mus., Tokyo, 2009
30 March-2 April 1961	Zc	2	Italy	4	Paulus, 1962[a]
April 1961	Md, Zc	3	US (Midway Island)	3	Galbreath, 1963
15-20 July 1961	Zc	2	France	4	Paulus, 1962[a]
10 July 1962	Ha	2	UK	4	Fraser, 1974
Jan-Feb 1963	Zc	5	Italy	4	Tortonese, 1963[a]
11-12 March 1963	Zc	5	Japan	3	Ishikawa, 1994[c]
11 May 1963	Zc	15	Italy	3	Tortonese, 1963[a, d]
12-13 June 1963	Zc	2	US (CA)	3	Mitchell, 1968
9 Nov 1963	Zc	15	Italy	2	Anon., 1963a[a]
2 Feb 1964	Zc	2	Japan	3	Brownell et al., 2004
18 Sept 1964	Ha	2	Scotland	4	Fraser, 1974
9 Dec 1965	Zc	5	US (PR)	3	Erdman, 1970[d]
20 Jan 1966	Ml	4	South Africa	4	Ross et al., 1989[d]
15 Nov 1966	Zc	3	Italy	3	Littardi et al., 2004[a]
16 March 1967	Zc	2	Japan	3	Brownell et al., 2004
5-7 Feb 1968	Zc	4	Bahamas	4	Caldwell & Caldwell, 1971
17 Aug 1968	Mb	3	Scotland	4	Sheldrick, 1989[d]
18-20 Aug 1969	Zc, Ha	2	Scotland	4	Sheldrick, 1989
6-7 Feb 1974	Mgr	3	New Zealand	4	Robson, 1975[d]
3 April 1974	Zc	4	Netherlands (Antilles)	5	Van Bree & Kristensen, 1974[d]
16-17 Dec 1974	Zc	2	France	5	Duguy, 1975; Viale, 1975[a, d]
21-22 Dec 1974	Zc	2	France	5	Duguy, 1975; Viale, 1975[a, d]
17 July 1975	Ms	3	US (AK)	3	Walker & Hanson, 1999[d]
4 Sept 1975	Mb	2	France	4	Duguy, 1976
6 Oct 1975	Ha	2	UK	4	Sheldrick, 1989[d]
4 Feb 1977	Mgr	3	New Zealand	4	Smithsonian Inst., 1978[d, e]
25 Jan 1978	Zc	9	Japan	3	Ishikawa, 1994

Dates	Species	Number cetaceans stranded per event	Country	Rank	References
March 1978	Msp	3	New Zealand	4	Smithsonian Inst., 1979[d, e]
17 Oct 1978	Zc	4	Japan	5	Ishikawa, 1994[c]
7 Nov 1979	Zc	13	Japan	3	Ishikawa, 1994[c]
15 Jan 1980	Zc	3	Bermuda	4	Smithsonian Inst., 1981[d]
28 July 1980	Ms	4	US (AK)	3	Walker & Hanson, 1999[d, e]
Jan 1981	Zc	3	Bermuda	4	Knap & Jickells, 1983[d]
18 July 1981	Ms	2	US (AK)	3	Walker & Hanson, 1999
Jan 1982	Mgr	8	New Zealand	4	Museum of New Zealand record
3 Jan 1982	Ml	3	Australia	4	Australian Department of Environment and Heritage
13-19 Dec 1982	Zc	3	France	4	Duguy, 1983
21 Jan 1983	Ml	2	Australia	4	Australian Department of Environment and Heritage
1 March 1983	Zc	6	Equador (Galápagos)	4	Robinson et al., 1983[d, e]
5 April 1984	Me	2	Cuba	4	Varona, 1985
25 Dec 1984	Bar	6	New Zealand	4	A. Baker, pers. comm., 22 March 2000[d]
16 Jan 1985	Ms	2	Japan	4	Ishikawa, 1994[c]
23 Jan 1985	Mh	2	Argentina	4	Lichter, 1986[d]
8 Feb 1985	Zc, Me	13	Spain (Canary Islands)	3	Vonk & Martín Martel, 1988[d, e]
13 March 1985	Ml	2	Australia	4	Australian Department of Environment and Heritage
Jan 1986	Mgr	2	Australia	4	Australian Department of Environment and Heritage[b]
1 June 1986	Zc, Me	5	Spain (Canary Islands)	4	Vonk & Martín Martel, 1988[d]
2 July 1986	Bb	7	Mexico	4	Aurioles-Gamboa, 1992[d]
29-31 Aug 1986	Mb	6	Canada (NF)	4	Lien et al., 1990[d, e]
11-15 Nov 1986	Ms	3	US (AK)	3	Walker & Hanson, 1999[d]
19 Dec 1986	Mgr	2	Australia	4	Australian Department of Environment and Heritage[b]
10 Feb 1987	Zc	2	Italy	4	Centro Studi Cetacei, 1988[e]
4 July 1987	Me	3	Spain (Canary Islands)	4	Martín et al., 1990[d]
16 July 1987	Zc	2	Japan	3	Ishikawa, 1994[c]
24 July 1987	Bb	4	Japan	3	Ishikawa, 1994[c, d, e]
15 Sept 1987	Msp	4	Greece	4	A. Frantzis, pers. comm., 27 Nov 1997[d]
15-18 Sept 1987	Mb	3	Canada (NF)	4	Lien et al., 1990[d, e]
10 Feb 1988	Mgr	15	New Zealand	4	Cawthorn, 1988[d, e]
19-20 June 1988	Hp	2	Australia	4	Australian Department of Environment and Heritage[b]
25 Nov 1988	Zc, Ha (+2 Kb)	4	Spain (Canary Islands)	2	Vonk & Martín Martel, 1989[d, g]
11-12 Dec 1988	Ms	2	US (AK)	3	Walker & Hanson, 1999
10 Jan 1989	Ts	3	Australia	4	Australian Department of Environment and Heritage[b, e]
29 Jan 1989	Zsp	2	Australia	4	Australian Department of Environment and Heritage[b, e]
4 Feb 1989	Ml	2	Australia	4	Australian Department of Environment and Heritage[b]

Dates	Species	Number cetaceans stranded per event	Country	Rank	References
21 Feb 1989	Zc	3	Japan	3	Ishikawa, 1994[c]
15-16 May 1989	Ml	2	Australia	4	Australian Department of Environment and Heritage[b]
19 Oct 1989	Zc, Me, Md	20	Spain (Canary Islands)	2	Simmonds & Lopez-Jurado, 1991; Martín, 2002[d]
27-28 Dec 1989	Mgr	2	Australia	4	Australian Department of Environment and Heritage[b, e]
5 Feb 1990	Ml	2	Australia	4	Australian Department of Environment and Heritage[b]
5 April 1990	Zc	6	Japan	3	Ishikawa, 1994[c]
4-5 Feb 1991	Zc	4	US (VI)	3	Mignucci-Giannoni & Rosario-Delestre, 1999[d]
11 Dec 1991	Zc	2	Spain (Canary Islands)	2	Martín et al., 2004
24 Jan 1992	Zc	3	Italy	4	Centro Studi Cetacei, 1995[a]
3-8 March 1992	Ms	2	Japan	4	Ishikawa, 1994[c]
25 June 1992	Zc	3	US (FL)	3	Walsh et al., 2001; R. Chase, pers. comm., 20 March 2006[e]
15 July 1992	Mb	3	Scotland	4	Sheldrick et al., 1994
3 Feb 1993	Zc	2	Taiwan	4	Wang et al., 1995
7 March 1993	Msp	2	Australia	4	Australian Department of Environment and Heritage[b, e]
20 April 1993	Zc	3	Greece	4	Drougas & Kommenou, 2001[a]
1 Oct 1993	Msp	2	Japan	4	Ishikawa, 1994[c]
19-20 Nov 1993	Zc	2	Greece	4	Drougas & Kommenou, 2001[a]
25 Dec 1993	Mgr	4	Australia	4	Australian Department of Environment and Heritage[b, e]
24 Jan 1994	Zc	2	Taiwan	4	Wang et al., 1995[e]
8-9 Feb 1994	Zc	2	Greece	4	Drougas & Kommenou, 2001[a]
27-29 Aug 1994	Ms	4	US (AK)	3	Walker & Hanson, 1999[d]
15 Nov 1995	Zc	2	Japan	3	Nat. Sci. Mus., Tokyo, 2009
25-26 Feb 1996	Zc	2	Spain	2	Blanco & Raga, 1997, 2000[a]
6-7 March 1996	Msp	2	Japan	4	Nat. Sci. Mus., Tokyo, 2009
12 April 1996	Zc	2	Greece	4	Drougas & Kommenou, 2001[a, e]
12-13 May 1996	Zc	14	Greece	1	Lefkaditou & Poulopoulos, 1998; Frantzis, 1998; Drougas & Kommenou, 2001[a, d]
16 Aug 1996	Zc	2	France	4	Oliver et al., 1997[a]; Van Canneyt et al., 1998[a]
14-17 April 1997	Msp	3	Japan	4	Nat. Sci. Mus., Tokyo, 2009[e]
28 June 1997	Me	2	Netherlands (Antilles)	4	Debrot et al., 1998
26 Aug 1997	Zc	3	Greece	4	Drougas & Kommenou, 2001[a, d, e]
2-5 Oct 1997	Zc	8	Greece	2	Drougas & Kommenou, 2001[a, d]
3 Oct 1997	Zc	4	Greece	2	Drougas & Kommenou, 2001[a, d]
7 Jan 1998	Bar	4	South Africa	4	Rice, 1998[d, e]
3 May 1998	Msp	2	Japan	4	Nat. Sci. Mus., Tokyo, 2009
29-30 July 1998	Zc	5	US (PR)	3	Mignucci-Giannoni & Rosario-Delestre, 1999[d]
10 Aug 1998	Ms	2	Japan	4	Nat. Sci. Mus., Tokyo, 2009
28 Aug-1 Sept 1998	Me	4	US (NC)	5	Norman & Mead, 2001[d]
14-16 Jan 1999	Zc	3	Greece	4	Drougas & Kommenou, 2001[a]
29 March 1999	Md	2	Japan	4	Nat. Sci. Mus., Tokyo, 2005

Dates	Species	Number cetaceans stranded per event	Country	Rank	References
30 May-3 June 1999	Ms	2	Japan	4	Nat. Sci. Mus., Tokyo, 2009[d]
3 Oct 1999	Zc	4	US (VI)	3	Ketten, 2005[e]
14-16 March 2000	Zc, Md, Me[f], Zsp (+ 2 Ba)	15	Bahamas	1	Evans & England, 2001; Balcomb & Claridge, 2001[d, e, g]
6 April 2000	Msp	4	Jamaica	4	G. Mitchell, pers. comm., 16 Feb 2001
11 April 2000	Zc	3	Equador (Galápagos)	4	Gentry, 2002[e]
5-10 May 2000	Ms	2	Japan	4	Nat. Sci. Mus., Tokyo, 2009
10-14 May 2000	Zc	3	Portugal (Madeira)	2	Freitas, 2004
7 Feb 2001	Zc	2	Algeria	4	Boutiba et al., 2001
8 March 2001	Msp	2	New Zealand	4	Anon., 2001[e]
19 April 2001	Zc	2	Turkey	4	Podestá et al., 2006
17 July 2001	Me	2	US (FL)	4	McCulloch, 2001
23 July 2001	Zc	2	Algeria	4	Boutiba et al., 2001
24-27 Sept 2002	Zc, Me, Md	14	Spain (Canary Islands)	2	Martín et al., 2004[e]
25 Sept 2002	Zc	2	Mexico	5	Taylor et al., 2004
14 Jan 2003	Mgr	6	Australia	4	European Cetacean Bycatch Campaign, 2003[e]
5 Feb 2004	Mgr	2	New Zealand	4	Anon., 2004[b]
21-26 July 2004	Zc	4	Spain (Canary Islands)	2	Fernández et al., 2004

[a]Also found in Podestà et al. (2006)

[b]Provided by Australian Defense Science and Technology Organization (29 May 2005)

[c]Also found in National Science Museum, Tokyo, Marine Mammal Stranding Database (2009)

[d]Also found in the Cetacean Distributional Database, Marine Mammal Program, Smithsonian Institution, Washington, DC, 2000

[e]Denotes stranding event in which some or all animals did not die (e.g., swam in harbor or were returned to sea)

[f]Report of Me as part of this event was listed in Balcomb & Claridge (2001) and not included in Evans & England (2001); *Stenella frontalis* was not considered part of the mass-stranding event in Evans & England (2001) and, thus, was not included.

[g]Contains non-beaked whale species, not counted in totals