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Mortality trends of stranded marine mammals on Cape Cod and southeastern Massachusetts, USA, 2000 to 2006

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ABSTRACT: To understand the cause of death of 405 marine mammals stranded on Cape Cod and southeastern Massachusetts between 2000 and 2006, a system for coding final diagnosis was developed and categorized as (1) disease, (2) human interaction, (3) mass-stranded with no significant findings, (4) single-stranded with no significant findings, (5) rock and/or sand ingestion, (6) predatory attack, (7) failure to thrive or dependent calf or pup, or (8) other. The cause of death for 91 animals could not be determined. For the 314 animals that could be assigned a cause of death, gross and histological pathology results and ancillary testing indicated that disease was the leading cause of mortality in the region, affecting 116/314 (37%) of cases. Human interaction, including harassment, entanglement, and vessel collision, fatally affected 31/314 (10%) of all animals. Human interaction accounted for 13/29 (45%) of all determined gray seal *Halichoerus grypus* mortalities. Mass strandings were most likely to occur in northeastern Cape Cod Bay; 97/106 (92%) of mass stranded animals necropsied presented with no significant pathological findings. Mass strandings were the leading cause of death in 3 of the 4 small cetacean species: 46/67 (69%) of Atlantic white-sided dolphin *Lagenorhynchus acutus*, 15/21 (71%) of long-finned pilot whale *Globicephala melas*, and 33/54 (61%) of short-beaked common dolphin *Delphinus delphis*. These baseline data are critical for understanding marine mammal population health and mortality trends, which in turn have significant conservation and management implications. They not only afford a better retrospective analysis of strandings, but ultimately have application for improving current and future response to live animal stranding.

KEY WORDS: Disease · Mass strandings · Necropsy · Cetaceans · Pinnipeds

INTRODUCTION

Strandings of marine mammals have occurred along the shores of the world's oceans for centuries (Aristotle 350 BCE, Thoreau 1864, Geraci 1978, McFee 1990). Every marine mammal species has been documented to single strand (Geraci 1978); in fact, what is known about some rare cetacean species has been derived solely from accounts of single strandings (van Helden et al. 2002). Significant aspects of historical and current scientific literature on marine mammals have been acquired through the investigation of stranded animals because strandings provide unique access to otherwise elusive species (Wilkinson 1991, Gulland et al. 1997, Colegrove et al. 2005). Consistent documentation of stranding events provides information on individual animal health but does not reflect the health status of an overall population. Records of strandings contribute to knowledge of the migratory range of various species and can also indicate changes in mortality patterns or

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***Cape Cod Stranding Network for study period

age structure in a population (Wilkinson 1991). In addition, marine mammals have long been recognized as sentinel species. The analysis of data and samples collected from stranded cetaceans and pinnipeds has also provided insights into ocean health (Duignan et al. 1996, Weisbrod et al. 2000, Nawojchik et al. 2003, Shaw et al. 2005, Wilson et al. 2005, Gulland & Hall 2007, Harper et al. 2007, Bogomolni et al. 2008, Lasek-Nesselquist et al. 2008, Pangallo et al. 2008). Data from the 2005–2006 portion of the present study (which covers 2000 to 2006) have been previously reported as part of a survey of live and dead marine mammals, fish, and birds (Bogomolni et al. 2008, Lasek-Nesselquist et al. 2008). Briefly, amplicons to sequences from *Brucella* spp., *Leptospira* spp., *Giardia* spp., and *Cryptosporidium* spp. were found in all taxa. Avian influenza was detected in a harp seal *Phoca groenlandica* and a herring gull *Larus argentatus*. Routine aerobic and anaerobic culture showed a broad range of bacteria resistant to multiple antibiotics. In all, 63/141 (45%) of stranded and 2/26 (8%) of by-caught animals in Bogomolni et al. (2008) exhibited histopathological and/or gross pathological findings associated with the presence of these pathogens.

Many populations have experienced significant declines not associated with excessive hunting (Taylor et al. 2007), as seen with the decline of the western stock of Steller sea lions *Eumetopias jubatus* (Loughlin et al. 1992, Merrick et al. 1994, Sease et al. 2001), several stocks of harbor seals *Phoca vitulina* in Alaska (Pitcher 1990), the southwestern stock of sea otters *Enhydra lutris* in western Alaska (Doroff et al. 2003), and Hawaiian monk seals *Monachus shauinslandi* (Antonelis et al. 2006). Additional studies have illustrated long-term effects on population health and ultimate decline caused by less-obvious human-related factors, such as contaminant loading. The effects of persistent organochlorine contaminants and heavy metals in marine mammals are known to cause immunosuppression (De Swart et al. 1995, Cámara Pellissó et al. 2008) and endocrine disruption (De Guise et al. 1995) and correlate with reproductive abnormalities (Reijnders 1986).

Relatively few efforts to systematically survey the cause of morbidity and mortality in stranded marine mammals have been made (Schroeder et al. 1973, Stroud 1979, Cowan et al. 1986, Steiger et al. 1989, Wilkinson 1991, Gerber et al. 1993, Greig et al. 2005, Zagzebski et al. 2006). Investigation into mortality trends could prove useful for accurately estimating population dynamics of marine mammals globally, and more specifically, in the highly impacted Cape Cod region. By attempting to better document and understand the causes of mortality, be they of human or non-human origin, a more effective system of population management might be achieved.

Cape Cod is a hook-shaped coastal land projection that extends into the Gulf of Maine. Within this gulf, areas of high productivity such as Stellwagen Bank offer important habitat for prey items consumed by marine mammals and thus attract large populations to the area around Cape Cod and southeastern Massachusetts throughout the year (Ward 1995). This near-shore foraging habitat, coupled with ideal haul-out sites along the coastline, make it prime habitat for several pinniped species to rest and pup. Pelagic cetacean populations known to aggregate on Stellwagen Bank also travel throughout Cape Cod Bay (Weinrich et al. 2001, Waring et al. 2007). Many of these species are gregarious in nature and frequently mass strand on the western shores of the northern extremity of Cape Cod (IFAW 2009). Historically this area is one of the highest impacted regions in North America in terms of mass strandings, with the frequency and number of events comparable to other cetacean mass stranding hot spots in the southeast USA, New Zealand, and Australia (Geraci 1978, Cordes 1982, Brabyn & McLean 1992, Brabyn & Frew 1994, Geraci & Lounsbury 2005, Bradshaw et al. 2006, Moore et al. 2007).

The objective of the present study was to create a system for categorizing causes of strandings and/or mortality specific to marine mammal species on Cape Cod and southeastern Massachusetts based on data collected over 7 yr. With this system, we can better understand the major causes of mortality within and among species and continue to monitor mortality trends and apply findings to future conservation efforts.

MATERIALS AND METHODS

Cape Cod, Massachusetts is located on the northeastern coast of the USA that extends into the Gulf of Maine in the Atlantic Ocean. The Cape Cod Stranding Network, now the Marine Mammal Rescue and Research Division of the International Fund for Animal Welfare (IFAW), is a member of the National Oceanic and Atmospheric Administration's (NOAA) National Marine Fisheries Service (NMFS) North East Regional Stranding Network and has been responsible for marine mammal stranding response along the shores of southeastern Massachusetts since 1998. The coverage region is estimated to be 1126 km of coast land, which includes all of Cape Cod in Barnstable County, the Elizabeth Islands in Dukes County, the southwestern coastal towns of Plymouth County, and all of the coastal towns in Bristol County (Fig. 1). The major bodies of water in the response region are Cape Cod Bay, the Atlantic Ocean, Nantucket Sound, and Buzzard's Bay.

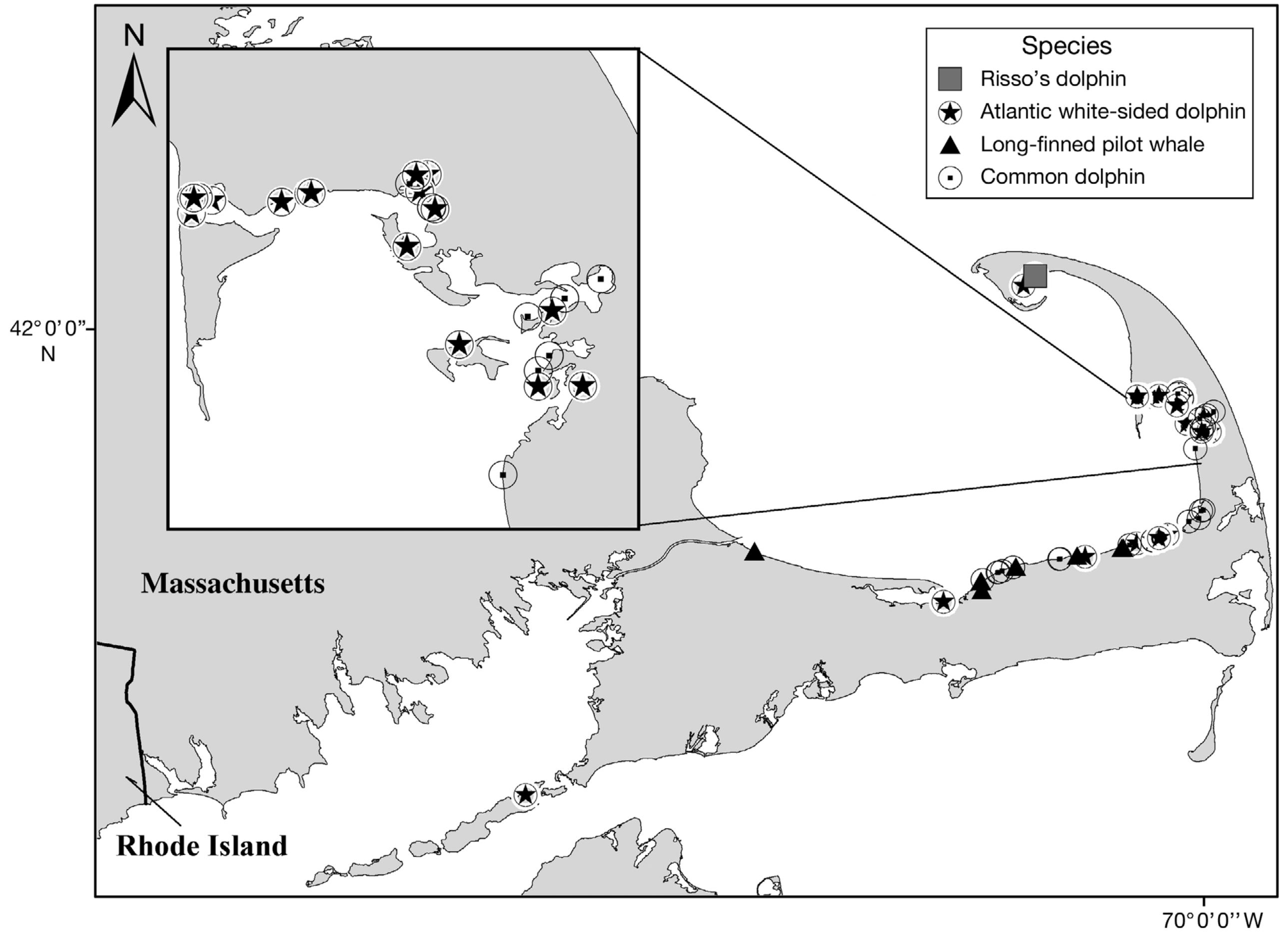

Fig. 1. Study area: Cape Cod and the southeast coast of Massachusetts, showing the distribution of MS NSF (mass stranding, no significant finding) cases by species. Insert: Wellfleet, MA, where most mass strandings occur. Each point represents multiple animals

IFAW has established systematic data collection protocols for both mass- and single stranding events, allowing for a consistent database from which substantial reliable information can be utilized for long-term analyses. Level A data, as required by NMFS (date and location of stranding, species, sex, age class, length, weight, human interaction, final disposition, and photo documentation), were gathered on all animals accessioned by IFAW. Information on the stranding event (behavior prior to and during stranding, physical condition, and weather) were also documented. More in-depth information (girth and blubber thickness measurements, tooth counts, and genetic samples) were collected on all carcasses when feasible. For animals that stranded alive, health assessments, including physical examination and blood-chemistry profiles, were conducted.

NMFS codifies decomposition levels of marine mammal carcasses by number and are described as such: Code 1: live animal; Code 2: fresh dead; Code 3: moderate decomposition; Code 4: advanced decomposition; and Code 5: mummified or skeletal remains. Post-mortem gross examinations were performed on all available fresh carcasses (Code 2) with preference to animals that were euthanized or for which the exact time of death was known. Investigation of carcasses in advancing stages of decomposition took place on a case-by-case basis or as required by a federally declared Unusual Mortality Events (UME). Necropsy techniques and sample collection (Pugliares et al. 2007) were performed or supervised by IFAW personnel to maintain consistency in data collection.

Samples for aerobic and anaerobic bacteria were collected using Fisherfinest™ Amies clear gel transport swabs (Fisher Scientific) and submitted within 24 h to IDEXX Laboratories (Grafton, MA) and plated on blood agar and MacConkey plates for aerobic culture, and blood agar, MacConkey, and anaerobic blood agar plates for anaerobic culture. Histology sample suites were collected and preserved in 10% neutral buffered formalin and submitted to the University of Tennessee, University of Connecticut, Mass Histology Services, Texas A&M, Northwest Zoopath, or the Armed Forces Institute of Pathology. Suspect *Brucella* sp. and suspect viral agents were sent to the United States Department of Agriculture (USDA) and the Oklahoma Animal Disease Diagnostic Laboratory (OADDL) for testing. Biotoxin analysis samples were sent to the Center for Coastal Environmental Health and Biomolecular Research (CCEHBR) Biotoxin Lab in Charleston, South Carolina. Computed tomography (CT) and magnetic resonance imaging (MRI) diagnostics were performed as circumstances permitted. Support for indicated analyses beyond gross pathology examinations increased in September 2005 as described above with regard to the previously published infectious disease aspect of these cases (Bogomolni et al. 2008). Where specific agents were suspected, immunohistochemistry, serology, and PCR assays were undertaken as appropriate.

The primary cause of death and/or stranding is defined as the condition most likely to have caused the animal's stranding and/or death based on all information recorded (Colegrove et al. 2005). When histopathology was available, cause of death was defined by the most significant finding as stated by the pathologist. For those cases where histopathology was not available, results from available ancillary investigation (e.g. microbiology, virology, hematology) and detailed gross descriptions were used to categorize as appropriate. At times only gross necropsy data were available. If gross changes were present and not obviously postmortem in nature, the most parsimonious diagnosis category was assigned as described in the next paragraph.

Of the 405 cases considered, cause of death could not be determined in 91 cases due to the lack of substantial data to confidently define a specific cause of death. The remaining 314 cases were categorized into 8 separate final diagnostic fields, defined as follows: (1) disease — disease processes such as neoplasia, idiopathic neurological conditions, or bacterial, viral, fungal or parasitic infections; (2) human interaction– harassment by people or pets, entanglement, fishery or vessel interactions, and/or debris ingestion; (3) mass-stranded with no significant findings (MS NSF) — no gross or microscopically significant findings other than conditions directly related to the mass stranding event; (4) single-stranded with no significant findings (SS NSF) — no gross or microscopically significant findings other than conditions directly related to the single stranding event; (5) rock/sand ingestion — ingestion of rocks and sand leading to impaction/dehydration, gastric ruptures, and peritonitis; (6) predation — wounds inflicted by canid, shark, or gull attacks resulting in death or humane euthanasia; weakening proximate conditions predisposing to predator attack were noted, but the immediate cause of death was attributed to predation if the underlying disease process was unclear as to cause; (7) failure to thrive and/or dependent pup or calf — emaciation/dehydration of very young animals believed to be separated from or abandoned by the mother; and (8) other — incidental conditions.

RESULTS

Table 1 summarizes the number of marine mammals in each diagnosis category by species. Table 2 compares the numbers in each diagnosis category between cetaceans and pinnipeds. Table 3 compares the number of disease diagnoses in each species in each year and Table 4 shows the number of each diagnosis in each year for all species.

Between 2000 and 2006, 1662 (mean 237 yr^{-1}) animals stranded along the coastline of Cape Cod and southeastern Massachusetts, 648/1662 (39%) of those being live animals. Of the 633 fresh carcasses (Code 2 at time of necropsy) available, a comprehensive necropsy was performed on 404/633 (64%), or 404/1662 (24%) of the total number of animals stranded. Histology samples were collected from 286/404 (70%) of necropsied carcasses. Histopathology results were obtained for 202/404 (50%) of cases where these samples were collected. The remaining histology samples are archived.

A total of 404 cases were reviewed for this study period (Table S1, available as supplementary material at www.int-res.com/articles/suppl/d088p143_app.pdf). In 91 cases, a definitive cause of death could not be determined. The 314 remaining cases (182 cetaceans; 132 pinnipeds) were reviewed and final diagnosis was determined as 1 of the 8 defined categories. Over the 7 yr report span, 16 species of marine mammals were evaluated to identify the cause of mortality. Totals of individual animals in each category were: disease (n = 115); human interaction (n = 30); MS NSF (n = 97); SS NSF (n = 11); rock ingestion (n = 10); predation (n = 24); dependent (n = 16); and other (n = 11) (Table 1).

Certain causes of mortality were found to be more common in some species than in others (Tables 1 & 3). When considered separately, cetaceans differed from pinnipeds in most common assigned diagnoses: the leading cause of mortality in cetaceans was MS NSF for 97/182 (53%) of animals, while disease, at 61/132 (46%) of animals, led for pinnipeds (Table 2).

Table 1. Number of marine mammals that stranded on Cape Cod and SE Massachusetts in each mortality diagnosis category by species between 2000 and 2006. MS: mass stranding; NSF: no significant finding; SS: single stranding

Common name	Species	Disease	Human interaction	MS NSF	SS NSF	Rock ingestion	Predation	Dependent pup/calf	Other	Total	% of all cases
Fin whale	*Balaenoptera acutorostrata*	0	2	0	1	0	0	1	0	4	1.3
Hooded seal	*Cystophora cristata*	8	2	0	1	1	1	1	1	15	4.8
Short beaked common dolphin	*Delphinus delphis*	20	0	33	1	0	0	0	0	54	17.2
North Atlantic right whale	*Eubalaena glacialis*	0	1	0	0	0	0	0	0	1	0.3
Long-finned pilot whale	*Globicephala melas*	4	0	15	0	0	0	2	0	21	6.7
Risso's dolphin	*Grampus griseus*	4	0	3	1	0	0	1	0	9	2.9
Gray seal	*Halichoerus grypus*	10	13[a]	0	1	0	2	1	2	29	9.2
Pygmy sperm whale	*Kogia breviceps*	1	1	0	0	0	0	0	0	2	0.6
Atlantic white-sided dolphin	*Lagenorhynchus acutus*	14	0	46[a]	1	0	2	3	1	67	21.3
White-beaked dolphin	*Lagenorhynchus albirostris*	1	0	0	0	0	0	0	0	1	0.3
Humpback whale	*Megaptera novaeangliae*	0	2	0	2	0	0	0	0	4	1.3
Harp seal	*Phoca groenlandica*	20	1	0	3[a]	9[a]	10[a]	0	5[a]	48	15.3
Harbor seal	*Phoca vitulina*	24[a]	6	0	0	0	4	4[a]	2	40	12.7
Harbor porpoise	*Phocoena phocoena*	7	2	0	0	0	5	3	0	17	5.4
Atlantic spotted dolphin	*Stenella frontalis*	1	0	0	0	0	0	0	0	1	0.3
Bottlenose dolphin	*Tursiops truncatus*	1	0	0	0	0	0	0	0	1	0.3
Total		115	30	97	11	10	24	16	11	314	
% of all cases		36.6	9.6	30.9	3.5	3.2	7.6	5.1	3.5		

[a]Species most affected in each category

Disease

Disease was the leading cause of mortality in 115/314 (37 %) of all stranded marine mammals (Table 3) and in 61/132 (46 %) of pinnipeds when considered apart from cetaceans (Table 2). Fatal disease processes were identified in 14 of the 16 species investigated (Table 1). *Phoca vitulina* (n = 24) were the most commonly diseased species at 24/40 (60 %). *Delphinus delphis* was the second highest represented species in this category with disease fatally affecting 20/54 (37 %) of examined animals. The disease processes most frequently found across species were bacterial pneumonia and sepsis/ bacteremia secondary to pyoderma. Verminous gastritis in pinnipeds and verminous pneumonia in both pinnipeds and cetaceans were also frequent findings and regarded as the immediate cause of death when severe. Neurological disease affected more cetaceans (n = 6) than pinnipeds (n = 2). Fatal neurological conditions included: necrosis of neurons consistent with hypoxia and brain edema (harp seal *Phoca groenlandica*), necrogranulomatous encephalitis (Atlantic white-sided dolphin *Lagenorhynchus acutus*), age-related neurodegeneration (*D. delphis*), meningoencephalomyelitis, meningoencephalitis, and non-suppurative polioencephalomyelitis (Risso's dolphin *Grampus griseus*). Other more unusual diagnoses included a single case of lymphosarcoma in *D. delphis*, an aspergilloma (*Aspergillus fumigatus*) in a long-finned pilot whale *Globicephala melas*, severe cholangiohepatitis in a harbor porpoise *Phocoena phocoena*, a diffuse fungal infection, endometritis, and placentitis in *L. acutus*, viral encephalitis in a *Phoca vitulina*, viral meningoencephalitis (morbillivirus) in a gray seal *Halichoerus grypus*, enteritis and otitis in *Phoca groendlandica*, epicarditis and enteritis in a pygmy sperm whale *Kogia breviceps*, and renal disease in a *D. delphis* (Table S1).

Human interaction

Human interaction was the cause of mortality in 30/314 (10 %) of all cases

Table 2. Number of cetaceans and pinnipeds that stranded on Cape Cod and SE Massachusetts in each diagnosis category between 2000 and 2006. MS: mass stranding; NSF: no significant finding; SS: single stranding; na: not applicable

	Disease	Human interaction	MS NSF	SS NSF	Rock ingestion	Predation	Dependent pup/calf	Other	Total
Cetaceans	53 (29)	8 (4)	97 (53)	6 (3)	na	7 (4)	10 (5)	1 (0.5)	182 (100)
Pinnipeds	62 (47)	22 (17)	na	5 (4)	10 (8)	17 (13)	6 (5)	10 (8)	132 (100)
Total									314

Table 3. Number of marine mammals that stranded on Cape Cod and SE Massachusetts per year diagnosed with disease as cause of death divided by total of all diagnoses

Species	2000	2001	2002	2003	2004	2005	2006	Total
Balaenoptera acutorostrata	0/0	0/0	0/0	0/1	0/2	0/0	0/1	0/4
Cystophora cristata	2/4	2/3	0/1	0/1	1/1	0/1	3/4	8/15
Delphinus delphis	1/1	2/2	2/4	4/4	4/7	1/20	6/16	20/54
Eubalaena glacialis	0/0	0/0	0/0	0/0	0/0	0/1	0/0	0/1
Globicephala melas	0/0	0/1	1/12	1/1	0/0	1/6	1/1	4/21
Grampus griseus	0/0	0/0	0/1	0/3	0/0	3/4	1/1	4/9
Halichoerus grypus	0/1	2/2	3/5	1/3	3/11	0/3	1/4	10/29
Kogia breviceps	0/0	0/0	0/1	0/0	0/0	0/0	1/1	1/2
Lagenorhynchus acutus	1/12	1/6	1/13	3/10	1/1	5/14	2/11	14/67
Lagenorhynchus albirostris	0/0	1/1	0/0	0/0	0/0	0/0	0/0	1/1
Megaptera novaeangliae	0/1	0/0	0/2	0/1	0/0	0/0	0/0	0/4
Phoca groenlandica	4/6	9/15	2/7	0/1	1/10	2/4	2/5	20/48
Phoca vitulina	1/4	5/8	6/8	2/4	3/3	3/6	4/7	24/40
Phocoena phocoena	0/0	0/2	1/2	3/4	0/1	2/7	1/1	7/17
Stenella frontalis	0/0	0/0	0/0	1/1	0/0	0/0	0/0	1/1
Tursiops truncatus	0/0	0/0	1/1	0/0	0/0	0/0	0/0	1/1
Total	9/29	22/40	17/56	15/34	13/34	17/66	22/51	115/314

Table 4. Number of marine mammals that stranded on Cape Cod and SE Massachusetts per year for each diagnostic category. MS: mass stranding; NSF: no significant finding; SS: single stranding

Diagnosis category	% of total	2000	2001	2002	2003	2004	2005	2006	Total
Disease	37	9	22	17	15	13	17	22	115
Human interaction	10	4	3	3	2	9	6	3	30
MS NSF	31	11	5	23	9	3	29	17	97
SS NSF	3	0	1	1	3	1	2	3	11
Rock ingestion	3	1	2	2	1	2	1	1	10
Predation	8	2	2	6	2	7	5	0	24
Dependent pup/calf	5	0	3	5	1	0	4	3	16
Other	3	2	2	0	1	1	2	3	11
Total	100	29	40	57	34	36	66	52	314

considered for the present study (Table 1) and fatally affected more pinnipeds (n = 22) than cetaceans (n = 8) (Table 2). Examples of confirmed human interaction cases included harassment by people or pets (n = 4), entanglement in netting or debris (n = 17, mostly in a monofilament net, but also large multifilament netting and other marine debris), vessel interaction (n = 6), and ingestion of debris (n = 3). *Halichoerus grypus* accounted for 13/30 (43%) of all animals within this diagnosis category, and 13/29 (45%) of all *H. grypus* in the present study conclusively died of human-related causes. The most common human interaction affecting this particular species was entanglement in fishing gear (n = 11) during the late spring and summer months along the southeastern shores of Cape Cod. Cases of harassment by people and pets involved primarily juvenile seals of various species.

Mass stranded with no significant finding

The leading cause of mortality of cetaceans (Table 2) was MS NSF, representing 97/314 (31%) of our complete sample set and 97/182 (53%) of all cetaceans (Fig. 2). During this report period there were 45 separate mass stranding events involving 373 individual animals from 5 species of cetaceans including *Lagenorhynchus acutus*, *Delphinus delphis*, *Globicephala melas*, *Grampus griseus*, and *Phocoena phocoena*. Ninety-two percent (97/106) of mass-stranded cetaceans included in the present study did not grossly or microscopically present significant findings other than conditions directly related to the stranding event. All but one of these cases occurred in Cape Cod Bay (Fig. 1). The most remarkable finding was that the majority of all *L. acutus* (44/67 [69%]), *D. delphis* (33/54 [61%]), and *Globicephala melas* (15/21 [71%]) fell into this category.

Single stranded with no significant finding

Eleven individuals from 8 species of marine mammals (6 cetaceans and 5 pinnipeds) fell into the SS NSF category of mortality, representing just 11/314 (4%) of the sample set. All cases were spread over the 12 mo calendar year.

Rock/sand ingestion

Three percent (10/314) of the animals analyzed had fatal gastric rupture, peritonitis, or severe impaction/dehydration directly related to the ingestion of rocks, pebbles, and/or sand. All animals within this category were pinnipeds, with 9/10 being juvenile *Phoca groenlandica*.

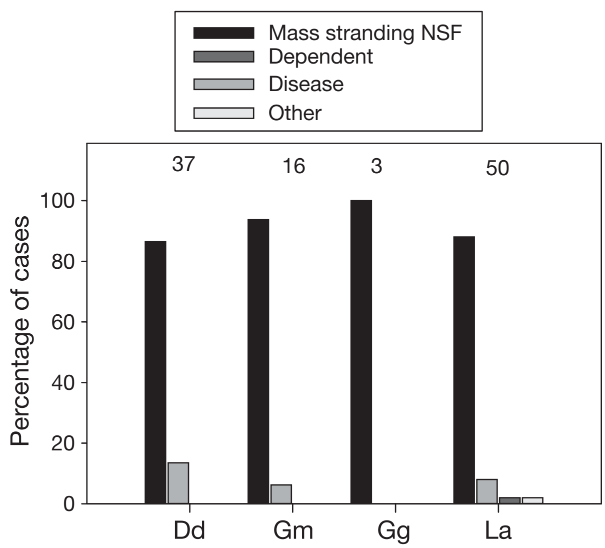

Fig. 2. Diagnosis of all mass stranded cetaceans examined from Cape Cod and SE Massachusetts beaches, 2000 to 2006. NSF: no significant finding; Dd: *Delphinus delphis*; Gm: *Globicephala melas*; Gg: *Grampus griseus*; La: *Lagenorhynchus acutus*. Numbers above each species are sample size for that species. Blank columns indicate zero findings for that category

Predation

Cases in which an animal was euthanized or died due to wounds suffered by canid, gull (mostly greater black-backed gull *Larus marinus*), or shark attacks accounted for 24/314 (8%) of our sample set and was found to be a cause of death in all 4 species of pinnipeds in the designated region as well as 2 small cetaceans (*Lagenorhynchus acutus* and *Phocoena phocoena*). The most common species represented in this category was juvenile *Phoca groenlandica*, with 9 out of the 10 suffering from the predation by canids. This category was the second most common cause of mortality in stranded *Phoca groenlandica* on Cape Cod and southeastern Massachusetts. Fatal predation by canids also affected *Cystophora cristata* (n = 1), *Phoca vitulina* (n = 3), and *Halichoerus grypus* (n = 1). Of the 5 *Phocoena phocoena* and 2 *Lagenorhynchus acutus* in this category, all 7 were preyed upon by gulls while live-stranded and were ultimately euthanized due to the severity of the wounds. There were only 3 cases of deadly shark attacks reported during this report period, all involving pinnipeds with hemorrhage and other signs of these attacks being pre-mortem.

Failure to thrive and/or dependent pup/calf

Failure to thrive or abandonment of a maternally dependent pup or calf was noted in 8 of the 16 species, with a total of 16 individuals falling into this category. The species most represented in this category was *Phoca vitulina* at 4/16 (25%); however, there were more cetaceans (n = 10) than pinnipeds (n = 6) in this diagnosis category.

Other

Cases in the 'Other' category accounted for just 11/314 (3%) of our sample set. This category included cases of mandibular fractures related to unknown trauma in 1 *Phoca vitulina* and 2 *Halichoerus grypus*, complications during pupping in 2 *P. vitulina*, rupture of intestines and uterus in a *Lagenorhynchus acutus*, diffuse congestion of internal organs in a *Cystophora cristata*, and heart failure, dehydration, and unknown trauma to *P. groenlandica*.

DISCUSSION

Primary cause of death of stranded marine mammals in the study region varied between years (Table 3). Depending on the condition of the carcass and available resources, the extent to which each case was investigated ranged from gross necropsy only, to gross and histological morphology, microbiology, and other analyses. Thus the specificity to which each diagnosis identified the cause(s) and/or consequence of factors leading to death likewise varies. For instance, many of the bacterial conditions described may have been secondary to undiagnosed viral infections, and gull predation on single-stranded cetaceans will have been secondary to undetected underlying causes of the beaching. Likewise, emaciated animals that had one or more pathological lesion were classified in the disease category, even if the proximate cause of the mortality was unclear. However, the available data did enable classification into the broad categories. Such relatively broad classifications inevitably obscure the fact that each mortality results from the sum of the environmental and genetic events impacting each animal for its entire life, each of which adds different degrees of causation to its final demise. Indeed the categories reflect those conditions that are readily observed by gross examination and ancillary laboratory studies, but may not accurately reflect a specific cause of death or pattern of mortality. This caveat is an inevitable product of the finite resources available to examine any one case.

The categories chosen are a combination of epidemiology factors (mass versus single strandings), etiological (infectious disease), human interactions, age, predation, and others. The categories generated a system of mortality categories that could or could not be managed by ecosystem managers. For instance, highlighting fishing gear entanglement enables potential management changes, whereas the broad disease category 'human interaction' is less manageable. There are certainly more subtle human-derived stressors, such as sewage effluent, that undoubtedly affect specific disease entities.

Disease

Disease was the leading cause of mortality for stranded marine mammals in the study region between 2000 and 2006. This category can be further broken down into specific disease processes, the most prevalent being bacterial/fungal pneumonia, septicemia/bacteremia caused by pyoderma, and verminous infections. The presence of bacterial pneumonia was common in both cetaceans and pinnipeds over the report period. There was no obvious pattern in terms of distribution of pyoderma, with a variety of factors including lice, demodicosis, and lacerations, often with secondary sepsis. Overall, sepsis secondary to skin infection was a common finding; however, there was a peak occurrence in pinnipeds in 2001. Thirty percent of all seals categorized under disease in 2001 had a fatal case of septic pyoderma. In hindsight, this probably suggests that specific factors in 2001 such as variations in air or water temperature or conditions at haul-outs could have influenced the prevalence of pyoderma, although it could have been an extreme of normal variation. Previous studies have correlated severe skin conditions of seal species to environmental contaminants or metabolic disease (Beckmen et al. 1997). Such findings are a good example of how long-term studies enable the retrospective identification of changing mortality patterns.

The presence of parasites in marine mammal populations is a common finding (Geraci & St. Aubin 1979). Immediate cause of death from parasitism affected more juveniles than adults, with all of the adults affected being cetaceans. It is unclear if this difference is due to development of an immune response, death of those younger individuals that are heavily parasitized, or some other process. Verminous gastritis was found only in pinnipeds, parasitic infestation of the brain was only present in cetaceans, and verminous infestations of the pulmonary system were equal between the groups. Parasites identified in these cases include *Otostrongylus* sp., acanthocephalans, and *Anasakis* spp. Generic identification of the parasites causing mortality has resulted in a better understanding of both the presence and the extent of infestation (normal, moderate, or heavy loads). Identification to species is an important next step. Further important questions include why verminous gastritis was only found in pinnipeds and parasitic brain lesions only in cetaceans.

Another observed trend is an apparent increase in *Delphinus delphis* mortality caused by disease processes (Table 3). There was no one specific disease found within this species; however, such a trend warrants close monitoring to identify the possibility of emerging diseases within this population.

Additional temporal trends included an increase up to 2006 of cases diagnosed under disease (n = 22) (Table 3). Diagnoses were more varied than the 2001 seal pyoderma peak. These included phocine distemper virus (PDV) in a *Halichoerus grypus*, glomeronephritis in one *Lagenorhynchus acutus*, and cervicovaginolithiasis in a *Delphinus delphis*. This trend could be attributed in part to increased ancillary diagnostic analyses during the last 16 mo of the present study (Bogomolni et al. 2008, Lasek-Nesselquist et al. 2008, Rose et al. 2009).

Mass stranding

Many hypotheses have been posed concerning the causes of mass strandings: pursuit of prey (Dudok Van Heel 1966, Sheldrick 1979), predator avoidance (Cordes 1982), geomagnetic force along the seafloor (Kirschvink et al. 1984, Klinowska 1985), and damage to the middle ear caused by the presence of parasites (Ridgway & Dailey 1972). Other theories have been supported by data collected during mortality events in specific regions: disease (Geraci 1978), harmful algal blooms (Fire et al. 2007), and disorientation caused by underwater sound (Parsons et al. 2008). Despite the plausibility of these theories, behavioral, clinical, and post-mortem investigation surrounding mass strandings on Cape Cod have yet to support these ideas.

Five species of small pelagic cetaceans mass-stranded during the present study period, with the most frequent events involving *Delphinus delphis*, *Lagenorhynchus acutus*, and *Globicephala melas*. Given that 97/106 (92%) of all mass-stranded cetaceans did not present with significant pathological findings upon post-mortem investigation, we concluded that these animals were relatively healthy prior to stranding and expired due to conditions directly related to the stranding event (e.g. extreme stress and shock, inability to thermoregulate, compression of internal organs). Similar findings have been reported elsewhere (Mead 1979, Cordes 1982, Gales et al. 1992, Wiley et al. 2001, Geraci & Lounsbury 2005). These data suggest that disease is not a driving factor in mass stranding events in this region and that other natural, non-pathological reasons may be involved. Like Cape Cod, areas of New Zealand and Australia where mass strandings frequently occur are also hook-shaped coastal land projections characterized by gently sloping beaches, and extended sand/mud flats. These similarities suggest that this complex coastal topography may cause navigational difficulty for certain social pelagic species and as a result could be one of the central factors causing mass strandings in these specific regions (Dudok Van Heel 1966, Mead 1979, Sheldrick 1979, Cordes 1982, Dawson et al. 1985, Wiley et al. 2001).

Although 97/106 (92%) of mass-stranded cetaceans showed no significant findings upon gross and histological examination, there were mass-stranded individuals that presented with pathologies. For example, an adult female *Delphinus delphis* that mass-stranded was diagnosed with age-related neurodegeneration, increased presence of microglial cells, Alzheimer's Type II cells, and corpora amylacea suggestive of cognitive dysfunction. The degree to which these compromised individuals influenced the entire pod to enter shallow water was not clear. Two studies (Wood 1979, Odell et al. 1980) support the hypothesis that mass strandings of apparently healthy cetaceans are related to behavioral tendencies of the pod to follow a lead animal. One post-mortem investigation of a *Lagenorhynchus acutus* mass stranding that occurred in Ireland revealed that 18 of the 19 animals appeared to be in moderately good health while one, the largest animal and also the first to strand, had significant pathology (Rogan et al. 1997). The 'follow a lead animal' mentality results in strong social cohesion and has been observed in free-swimming and stranded pilot whales (Cordes 1982, Dawson et al. 1985, McLeod 1986, McFee 1990). Additional investigations into pod behavior prior to stranding as well as improved understanding of the complex social structure of species that mass strand could provide relevance for this theory on Cape Cod.

In addition to the influence of coastal topography and social cohesion, disorientation caused by severe weather fronts and oceanographic conditions is also a credible cause for mass strandings globally and on Cape Cod (Cordes 1982, Parry et al. 1983, Evans et al. 2005, Geraci & Lounsbury 2005). Storm fronts driven by strong northeast winds are common occurrences on Cape Cod during the winter and spring. Several mass strandings occurred during these storm events. For example, in December 2005 a large mass stranding event involving 45 animals of 3 delphinid species occurred along multiple beaches during a microburst storm with winds gusting at >100 miles h^{-1} (>160 km h^{-1}) throughout outer Cape Cod.

Human interaction

Over 45% of all mortality in gray seals *Halichoerus grypus* was attributed to human interaction. Across species, the most documented type of human interaction was entanglement occurring along the Nantucket Sound and southeast sides of the outer Cape region. This area coincides with one of the largest seal haul-out sites on the northeast US coast, Monomoy National Wildlife Refuge. Human interaction cases also involved severe harassment of juvenile seals, including the capture and transport of one *Phoca vitulina* pup almost 80 miles (130 km) in the back seat of a beach-goer's automobile. More commonly, physical intervention by the general public involving attempts to move seals back to the water caused negative physical effects on the animal by increasing their stress levels. Both situations, entanglement in marine debris and harassment, have the potential to be mitigated through community education programs. More formal policy and management actions may be necessary to decrease fishing-gear interactions.

Cause of death in large whales included in the present study was largely due to human interaction (5/9), namely vessel collision (n = 2) and entanglement (n = 3). Ship strike was the cause of death in a single 9 yr old female North Atlantic right whale *Eubalaena glacialis*. Upon gross examination, the carcass presented severe subdermal bruising along the right flank, with substantial fractures of the underlying vertebrae. The most cranially affected vertebra was fractured across the centrum and neural spine. A second case, a minke whale *Balaenoptera acutorostrata* carcass, presented with subdermal hemorrhage at the right axilla and scapula, mandible, and tongue, and also revealed the presence of a full stomach and reflux, suggesting that this animal was feeding at time of impact. Cause of mortality was likely collision with a small vessel. The cases of entanglement in *B. acutorostrata* and humpback whales *Megaptera novaeangliae* presented with severe abrasion and inflammation of the skin, blubber, and muscle layer around the rostrum and leading edges of the flippers and flukes. Documentation of specific interactions with particular species allows management agencies to implement more targeted changes by industry and location.

Predation

Pinniped mortality by predation follows a seasonal trend, with most canid predation events occurring in winter months and shark predation occurring during summer months. Cases of canid predation are almost exclusively consistent with coyote rather than domestic canid attack (one case involving a domestic dog was considered a human interaction). Canid predation (14/24) affected predominantly *Phoca groendlandica*, which frequents Cape Cod during the winter months. The eastern coyote *Canis latrans* is a non-native inhabitant of Cape Cod and was (in recent times at least) first documented in the region in the 1980s; the prevalence of this species steadily increased through the 1990s (Way et al. 2004). However, due to the saturation of the available land by human development, there has been a plateau in population growth (J. Way pers. comm.). IFAW staff first observed a case of possible coyote predation upon a *P. groendlandica* on Cape Cod in 2000 and a later occurrence was confirmed in 2002 (Way & Horton 2004). Since 2000, these findings have dramatically increased, most likely due to increased awareness and experience of stranding response staff in evaluating carcasses for signs of predation. This increase may also reflect coyotes relying more on hauled-out seals as a food source in winter when the volume of harp seals in the area is greatest. Documentation of these interactions is important in order to understand the interactions of pinnipeds and their predators as well as the potential for disease transmission between terrestrial and aquatic species (Forsyth et al. 1998, Daszak et al. 2000, Webster et al. 2002). Rabies is uncommon but not unheard of in Cape Cod coyotes (Gershon 2005).

Gull-predation cases presumably reflect situations for which an underlying condition weakening the animal was undetected. This may also be true with canid and shark attacks.

Rock/sand ingestion

Results clearly indicate that *Phoca groenlandica* were by far the predominant species whose cause of death was due to ingestion of sand and/or rocks. The ingestion of rocks and sand in ice seals is a common finding within this geographic region and is likely a behavioral response to stress. Knowing that ingestion of rocks and sand is a behavioral response of ice seals, stranding networks can potentially minimize stress to the animal by increasing public education and using signage and patrolling to keep people away from the seal.

Conclusions and conservation relevance

Categorizing the causes of death is a valuable tool for monitoring mortality trends of marine mammal species that strand on Cape Cod and southeastern Massachusetts. Since disease was the leading cause of mortality, it is important that disease surveillance protocols are continued and should be a primary focus in marine mammal stranding science, with enhanced laboratory efforts to better define specific pathogens. The cases examined here represent only animals which died or were euthanized as IFAW-accessioned cases. IFAW does not provide long-term rehabilitation for marine mammals, and therefore depends on the resources available within the wider northeast-region stranding networks for this goal. By using this system of mortality analysis, standardized necropsy protocols (Pugliares et al. 2007), histopathology, and further disease diagnostics, results throughout the region can be compared regardless of initial and subsequent stranding response facility, allowing for a more comprehensive determination of marine mammal mortality. Additional information that would facilitate more conclusive determinations for cause of mortality in the cases presented in the present study include histopathology on all cases, contaminant analysis, genetics, aging, immune function, and microbiology.

Bystanders at local mass stranding events often speculate about the possible role of military sonar. Lesions in beaked-whale mass strandings associated with mid-frequency naval sonars include severe diffuse congestion, diffuse congestion and hemorrhage, especially around the acoustic jaw fat, ears, brain, and kidneys, and gas bubble-associated lesions and fat embolism in the vessels and parenchyma of vital organs (Fernandez et al. 2005). The absence of such lesions as a cause of death in this region, in conjunction with the apparent absence of local military exercises, suggests that the Cape Cod region could serve as an important reference area for regions with greater episodic acoustic activity.

Cetaceans and pinnipeds follow different life-history patterns and are thus exposed or susceptible to different factors that may result in death. In the present study, the most common cause of death in cetaceans was MS NSF (otherwise healthy animals suffering only from the effects of the stranding itself). Therefore, for cetaceans in this region, the primary conservation focus should be on mass stranding prevention and response efforts. On a species-specific level, entanglement in fishing gear was the leading cause of mortality in *Halichoerus grypus.* Marine mammal deaths due to human interaction are perhaps the most striking because they are, theoretically, completely avoidable. In the past, disentanglement efforts have been undertaken by IFAW with varied success due to the logistical challenges of such a program. However, these efforts do not address the root of the issue. The most effective ways to decrease the mortality of gray seals due to entanglements are to (1) develop more selective recreational and commercial fishing practices, and (2) increase education on the impacts of ghost gear and other marine debris.

The present study illustrates the importance of reliable, standardized methods for documenting mortality in marine mammals. An increased understanding of the causes of stranding and/or mortality in marine mammals can inform progressive stranding-response protocols to increase the survival of animals that strand alive. This system also allows stranding staff to more efficiently collate and analyze mortality data for their particular region, providing a useful tool in determining where conservation efforts should be focused.

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