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Capstone of
Octavia Williams

Submitted in Partial Fulfillment of the Requirements for the Degree of

Master of Science

M.S. Marine Biology

Nova Southeastern University
Halmos College of Natural Sciences and Oceanography

May 2018

Approved:
Capstone Committee

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Nova Southeastern University

Halmos College of Natural Sciences and Oceanography,

Department of Marine and Environmental Science

Biological and abiotic factors influencing cetacean mass strandings in the Northeastern United States

By
Octavia M. Williams

Submitted to the Faculty of Nova Southeastern University
Halmos College of Natural Sciences and Oceanography
in Fulfillment of the Requirements for the
Degree in Masters of Science for

Marine Biology

April 2018

Acknowledgments

I would like to thank the members of my committee, Dr. Riegl and Dr. Kerstetter, whom despite their strenuous schedules and special circumstance accepted me as an advisee at the final hour, providing guidance and suggestions throughout the completion process. In the memory of Dr. Edward Keith, I would like to thank Dr. K. for his continued patience, support, encouragement, and enthusiasm throughout my tenure at Nova Southeastern University (NSU) as I worked to complete my research between 2005– 2007. Thank you, Mark Murray-Brown and Mendy Garron from the National Marine Fisheries Services, Northeast Regional Office (NERO) for providing me with the critical resources needed for this study. I would like to especially thank Mendy Garron, NERO's Marine Mammal Stranding Response Program Coordinator, for providing the data and granting me authorization to utilize the northeast regional information for my analysis. Without the help of these dedicated professionals I would not have been able to conduct the statistical analysis portion of my research. I've gained an extraordinary appreciation for biological oceanography upon the completion of my studies at NSU. In addition, I thank Dr. Sam Purkis and Meghan Bills whom assisted in my better understanding of Globalmapper, enabling me to produce the stranding site maps displayed/included in this report.

Finally, I would like to thank my family. To Carl Poole, thank you for your love, support, and understanding. For listening to my complaints and letting me know you were proud of me then and now. To my parents, James and Anita Williams, thank you for your "tough" love, constant push, and persistent faith in me that I can get through this. Without them I would have never been motivated enough to complete the research journey or this program.

Abstract

Marine mammal strandings are frequent occurrences along many coastal areas around the world. The significance of stranded cetaceans has been of interest since around 300 B.C. when philosophers, like Aristotle, pondered why marine mammals, including whales, dolphins and porpoise beach themselves; and famous authors, like Henry David Thoreau, whose fascination in mammal strandings lead him to write a book about these mass occurrences off the coast of Cape Cod. Numerous hypothetical theories have been developed to explain these mass stranding phenomena. Though the causes of mass strandings remain unresolved, recent investigations suggest contributing factors could include environmental elements. Less emphasis has been placed on the importance of biological factors while increasing research has been conducted on how seasonal fluctuation and geographical location influences the number of mass strandings. Major studies have focused on mass stranding events along the southeast region of the United States (North Carolina to Florida) with less focus on the northeastern regions (Virginia to Maine). Stranding data from 1988-2006 in the Northeastern United States, collected by the National Marine Fisheries Service (NMFS) and the Cape Cod Stranding Network (CCSN), show a peak in mass stranding frequency along the coast of Massachusetts during the winter and spring seasons. With mass stranding events continuing along the eastern coast of the United States, data suggests that multiple factors coexist for a stranding (single or mass) to occur. Throughout this report, scientific theories are reviewed correlating seasonal changes, wind circulation patterns, geographical location, and parasitic infections as potential causes of mass stranding events. Seasonal variations have been proven to influence wind direction and speed, creating frontal convergences in the ocean environment. These changes when tracked by cetaceans may navigate them into shallow shoreline areas. Strandings in the northeast United States are more likely to occur on beaches with sloping typography, increased sand accumulation, and regions with elevated coastlines, allowing pockets of deep water to be located near the shore (Klinowska, 1985). In addition, biological samples obtained during necropsy procedures from deceased mammals throughout the eastern United States revealed high levels of parasitic infections within these animals' cranial sinuses and brain cavities – areas which are known to directly affect marine mammal neurological and navigational capabilities . A combined literature review suggests that many of these biological and environmental factors need to be considered as potential contributors during the initial stages of cetacean stranding events.

Keywords: Mass Strandings, Abiotic factors causing mass strandings, Marine Mammal strandings, Cause for mass strandings, Cetacean Strandings. Biological factors causing strandings

Statement of Purpose

Through research of several mass stranding events in the northeastern United States from 1988-2006, I'll explore what environmental and biological factors caused these mass strandings. This analysis and literature review will discuss how abiotic factors (including seasonal variance and coastal topography) as well as biological factors (including parasitic infections) can potentially influence cetacean mass stranding in the United States. The value of this work is to educate and assist with further development of stranding management plans, including accurate response protocols, to reduce the number of fatal mass strandings of marine mammals along the northeastern coast of the United States.

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Introduction

A stranding can be defined as an event in which marine mammals are found immobile along ocean coastlines and unable to reenter their ocean environment. There are two types of stranding: a single stranding, defined as an event in which one marine mammal is located outside of its natural habitat on land, and mass stranding (Figure 1), in which a group of animals of the same species come ashore at the same time (occasionally over an extended period of time including up to days) and within the same vicinity (Berta *et al.*, 2006). Some scientists believe that single-animal strandings are a consequence of disease and these animals are brought to shore passively, while mass strandings occur actively. Recent records show that the majority of strandings on the coast of the northeastern United States, encompassing Maine to Virginia, consist of the stranding of cetaceans, including both the larger whales and the smaller species, including dolphins and porpoises.

For centuries, the occurrence of these stranded cetaceans has been of interest to humans. In the English translation of. *Historia Animalium* (1970), an excerpt provided by Aristotle states, "It is not known for what reason they run themselves aground on dry land; at all events, it is said that they do so at times for no obvious reason." The question of why marine mammals come ashore and why in such high numbers have mystified philosophers, natural historians, and biologists for centuries. Although many marine mammals strand individually, it is mass strandings that raise the most concern and intrigue. In North America, only a few cetacean species are known to strand in mass groups, defined as greater than 15 individuals. These species include pilot whales (*Globicephala* spp.), sperm whales (*Physeter macrocephalus*), Atlantic white-sided dolphins (*Lagenorhynchus acutus)*, false killer whales (*Pseudorca crassidens)*, rough-toothed dolphins (*Steno bredanensis)* and white-beaked dolphins (*Lagenorhynchus albirostris*). Cetacean species that strand more occasionally tend to be in smaller numbers and are species that are pelagic or less commonly associated with inshore waters (Geraci and Lounsbury, 2005).

Disease, temperature, availability of prey, and wind patterns are all thought to contribute to the increase in mass stranding events (Perrin *et al*., 2002). For example, the

forced movement of water due to wind may affect where prey is located, as well the location and movement of frontal convergences. Ultimately, the cause of cetacean strandings remains unclear; though there have been numerous theories advanced, few are supported by concrete evidence (Walker *et al*., 2005). There is not a single conclusive explanation that accounts for all of the single and mass strandings around the world.

Current stranding research has helped develop conservation alternatives that can lead to the decrease of single- and mass mammal stranding events. Unfortunately, with increased scientific monitoring, worldwide statistical analysis has led scientists and conservationists to draw parallels to a continuous increase in cetacean strandings over the past few decades. In the United Kingdom, the National History Museum records show that both single and mass strandings have increased from 360 in 1994 to 422 in 2004 (Bradshaw *et al.,* 2005). In Australia and New Zealand, statistics recorded in the 1920s show less than 20 stranding occurrences annually, while records from 2004-2005 in New Zealand show more than 20 marine mammal strandings, primarily dolphins, in a single area alone, with a total of more than 80 stranding events recorded for the country that period (Bradshaw *et al.,* 2005). With the continuous increase of strandings in these areas, as well, as noted in the Bradshaw *et. al*, report, more international innovative and skillful approaches are needed to reduce these stranding events.

U.S. scientists have noted that the topography of certain landmasses where cetaceans strand is just as important as the conditions in the water. There are areas within the United States known for repeated mass stranding events, the most famous of these is Cape Cod, Massachusetts. (Walsh *et al*., 2001). Between 1981 and 1991, ten separate mass stranding events occurred within a 20-mile radius along Cape Cod's coast. These strandings totaled more than 475 animals beached, primarily between the months of September and December (Geraci and Lounsbury, 1998).

Collectively, the efforts of numerous research facilities and formally developed global stranding networks have assisted in saving the lives of thousands of stranded mammals. With the increase in the number of cetacean strandings, researchers in association with stranding networks and research facilities work diligently to develop successful techniques, including but are not limited to necropsy tissue banking, and to enhance stranding-response times in order to increase the survival of marine mammals.

The driving force behind the creation of stranding networks stems from public concern for stranded marine mammals along with the need to obtain maximal research data for further study approval and conservation efforts (Gulland *et al*., 2001). The importance of stranding networks and the amount of information obtained from these organizations has been profound and affected conservation in the following ways.

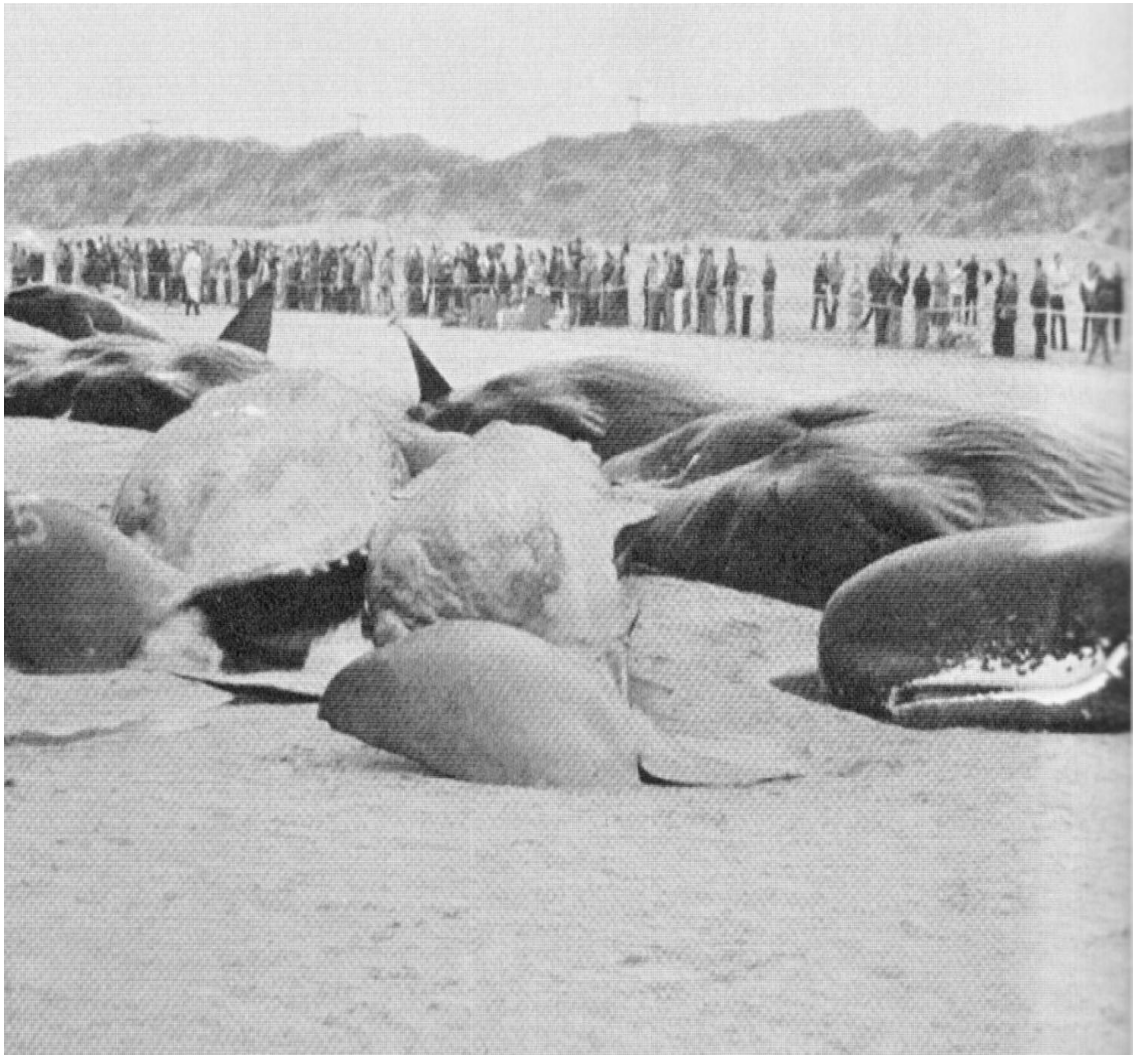


Figure 1. Mass stranding event of sperm whales (Berta *et al.*, 2006).

Some early theories gleamed from the collective data of the last century to explain strandings include: mammals' confused echolocation, following prey ashore, environmental stressors, increased fluctuations in the oceans saline environments, and the response to geological activities that resemble distress calls (Geraci *et al.*, 1999; Odell, 1987). Amongst studies on stranding occurrences and locations, a common concurrence shows that stranding events may be substantially affected by factors. These factors include - disease and parasites, changes in weather patterns, coastal configurations, and geomagnetic fields. Additional contributory factors may include: discoveries of increased levels of parasitic infestations within deceased stranded cetaceans, meteorological events such as electrical storms, strange configurations of coastal shorelines, and the nature of a magnetically induced shift of the seafloor (Warneke, 1983).

Though there are no collectively accepted theories, researchers continue to study the multiple factors that may contribute to single and mass stranding events in an effort to provide conservation and management tools (Walker *et al.*, 2005). This review focuses on the possible biological and abiotic factors such as disease, temperature, ocean circulation patterns and seasonal weather changes that may contributed to or caused mass stranding events on the northeastern coast of the United States (Figure 2), with special emphasis on Massachusetts, with the highest reportable mass stranding events (Figure 3) between 1988 and 2006.

Figure 2. Satellite map of the northeast sector of the United States (Google Earth Pro)

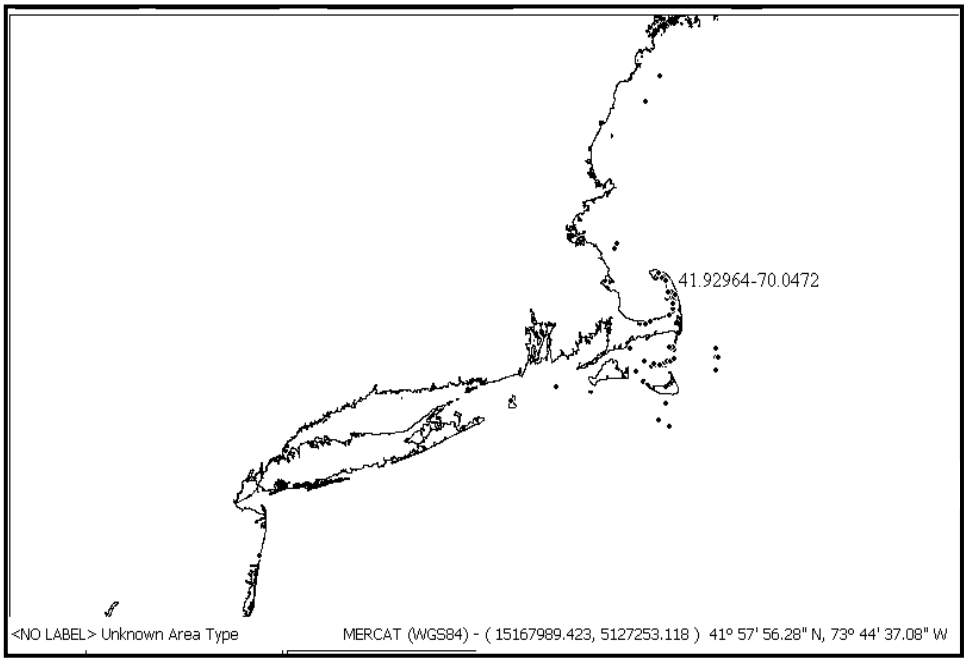


Figure 3. Map of stranding events along the Northeastern coastline of the United States from 1988 -2006.

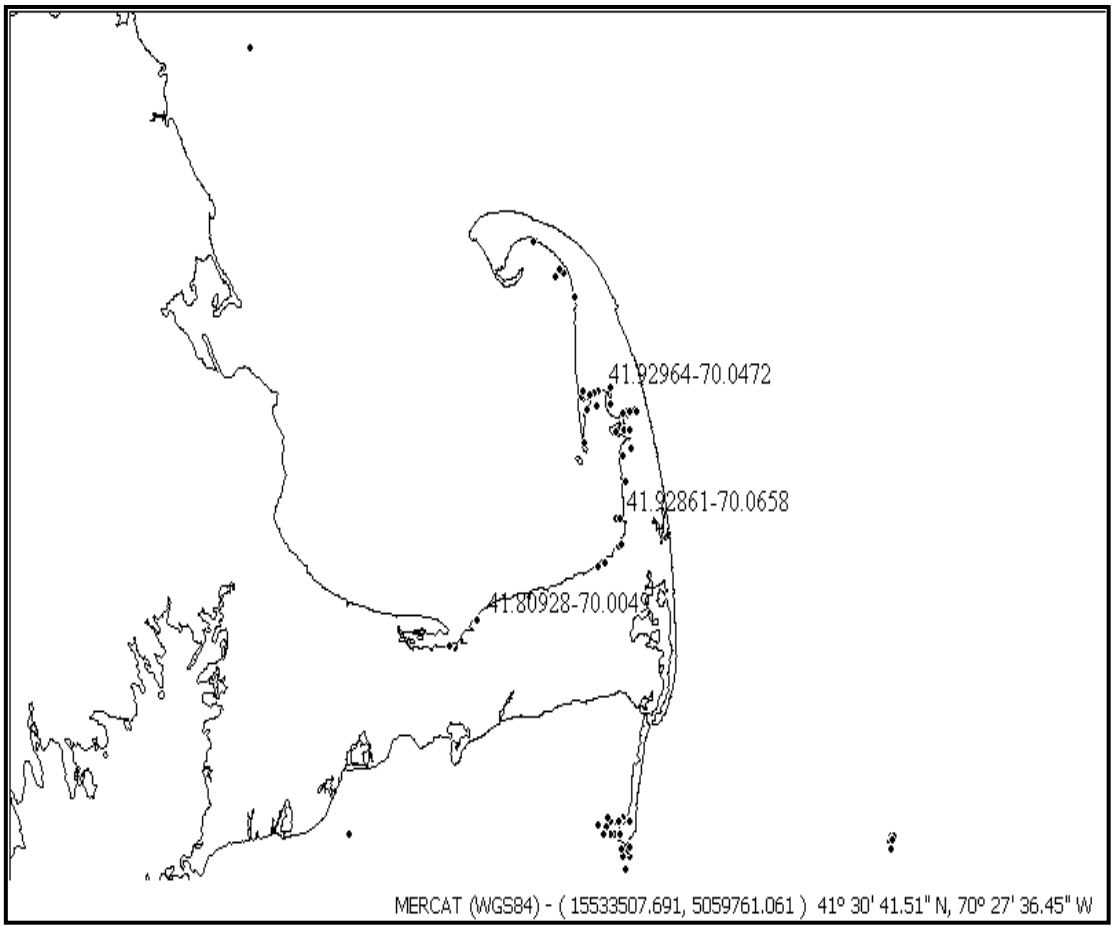


Figure 4. Map of mass stranding events in Massachusetts from 1988 -2006.

Seasonal Influence

An environmental factor that has not been thoroughly examined is the effect of seasonal weather changes on mass stranding frequencies. In multiple regions around the world, researchers have not been able to provide a general consensus of the peak season for mass stranding events. For example, strandings are more common in Puerto Rico and the U.S. Virgin Islands during the winter and spring months (Mignucci-Giannoni *et al.*, 1999). Nicol and Croome (1988) found a large peak in strandings in Tasmania during the midsummer months, typically during the period when cetacean species are migrating to their feeding grounds. Research conducted in Cape Cod shows some groups of longfinned pilot whales *Globicephala melas* tend to follow migrations of squid populations into shallow waters off Cape Cod Bay during the autumn months, which correlate with stranding occurrences annually (Perrin and Geraci, 2002). However, a correlation between these seasonal fluctuations was related to changes in meteorological factors such as sea surface temperature, an increase in rainfall, and the availability of prey species – all which peaked in the summer and decreased in the winter (Bakker and Smeenk, 1990). With continued global research, scientists might be able to determine whether migration, changes in habitat use, or weather patterns affect the seasonality of strandings. Subtle shifts in the relative abundance and distribution of strandings within southern "warmer" and northern "colder" waters may also be attributed to climate change and increasing ocean temperature (MacLeod *et al.*, 2005).

Strandings Influenced by Wind and Ocean Circulation Patterns

When reviewing weather patterns and fluctuations, temperature is not an isolated factor that changes with the seasons. An additional varying meteorological factor that changes in relation to seasons is the increase and decrease of wind influences on the ocean's circulatory patterns. Wind driven oceanic circulation patterns can affect up to the first 100 meters of the water column. Due to the Ekman transport, the net transport of water due to the mix of wind and surface water, in the Northern Hemisphere these circulation patterns travel 90 degrees to the right of the wind (Barber and Smith, 1981). Therefore, water mass travels perpendicular to the wind alongshore where wind produces

across-shore Ekman transport (Barber and Smith, 1981; Brink, 1991). Coastal divergence and convergence of the surface Ekman transport produces a decrease or increase in sea levels and coastal upwelling and downwelling (Brink, 1991). Coastal upwelling occurs when surface water is moved by wind forcing away from the shore and subsurface water is brought to the surface to replace the removed water mass. Downwelling, the opposite, occurs when water moves towards the shore is built up and is forced downwards near the coast. Depending on the direction of wind along the coast, conditions are either upwelling-favorable or downwelling-favorable. In Massachusetts, the average prevailing winds from July to September are upwelling-favorable along the coast and downwelling-favorable during the winter and early spring months.

Research has shown that cetaceans do respond to changes in water properties, making it quite possible for the upwelling and downwelling conditions to influence herd/pod positioning (Barber and Smith, 1981). Cetacean distribution tends to vary with the physical, chemical, and biological characteristics of water masses (Forcada, 2002). Water characteristics can vary with horizontal distance. There are large regions where horizontal variations are small, bounded by narrow regions where horizontal gradients are large. The high-gradient areas are referred to as fronts, and are important because higher biological activity is often associated with them (Mann and Lazier, 1991). Frontal convergences, upwelling fronts, seafloor relief, water depth, thermocline depth, topographic relief, water temperature and salinity are frequently used to describe differences in distribution of cetaceans (Polacheck, 1987; Gowans and Whitehead, 1995; Griffin, 1997; Forcada, 2002). The geographic distribution of cetaceans shift in response to the changing of habitats formed by eddies (a current of water moving contrary to the main current), thermoclines (a region of water that separates warm surface water from cold deeper water in which the temperature decreases rapidly), and fronts (boundary separating two masses of air with different densities) (Evans, 2002).

In areas of wind-driven upwelling, dense phytoplankton concentrations often develop around the uplifted pycnocline (an ocean layer in which the water density increases rapidly with depth) (Franks, 1992). Therefore, most fronts are areas with increase food source for cetaceans with enhanced plankton and fish production (Owen, 1981; Mann and Lazier, 1991). An increase in prey abundance at open-ocean eddies and fronts between differing water masses coincides with an increase in cetacean sightings

(Gowans and Whitehead, 1995; Griffin, 1997; Berta and Sumich, 1999; Fiedler, 2002; Forcada, 2002) during the late summer and early autumn months in Massachusetts. This correlation shows that the prey itself is not as important as the boundary areas in which marine mammals migrate, which causes dynamic zones of higher productivity and biomass (Franks, 1992; Griffin, 1997; Neumann, 2001).

Furthermore, cetaceans are known to follow temporal oceanic, climatic or biological phenomenon in the form of frontal zones, gyres, and upwelling areas (Bjorge, 2001). They are likely to be found in geographical areas such as Massachusetts where there are strong horizontal gradients. Oceanographic variants in these areas include water temperature, salinity, density, chlorophyll concentration, and thermocline depth (Forcada, 2002). In addition, thermocline depth has proven to be an important component in cetacean habitat variability and movement patterns (Fiedler *et al*., 1997; Neumann, 2001). Since cetaceans have the ability to locate frontal areas offshore, they tend to follow these frontal areas inshore to areas where productive water masses are located; subsequently, they may strand themselves on these local coastlines in search of food. Though it is highly unlikely that wind stress is the solo factor that causes stranding to occur, the direction of wind affects the properties of water in coastal areas. The extent of ventilation in the form of increased mixing, and the quality of the water in the area, will affect the fish assemblages, thus indirectly affecting cetacean distributions. If the marine animals are ill, they may concentrate on basic navigation methods, while overlooking others, and follow different water properties into an abnormal environment (Walsh *et al.,* 1990).

Biological Influence

Over the past few decades, scientific interest in the correlation of biological influences on cetacean mass strandings has waned; instead, surgically trained scientists have placed more emphasis on post-mortem examinations of marine mammal species to determine potential causes of illness or death (Walsh *et al.,* 1987). Multiple studies have been conducted to determine if there is a connection. The most common biological influences observed have been the linkage between pathological infections in stranded cetaceans. Parasitic-affected debilitation is one of the leading theories to explain

cetacean stranding behavior. Dailey and Stroud (1978) examined several types of parasitic infections found in stranded cetaceans off the Oregon coast (Table 1), and provided data that supports the theory that infectious diseases should be considered a major factor causing many cetacean strandings along the coastal United States. The results from the necropsies performed during this study confirmed that parasitic infections were a key contributor in approximately 33% of the recorded stranding deaths. Though it is noted, parasitic infections were also identified in the remaining species, primarily the cestode *Monorygma grimaldii*, no correlation was made identifying these parasites as key contributors to the remaining standing deaths.

Some major infectious diseases contributing to mass strandings globally were porpoise morbillivirus (PMV) and dolphin morbillivirus (DMV). Van Bressem *et al.* (2001) noted that PMV and DMV infections extinguished 50% of the inshore common bottlenose dolphins (*Tursiops truncatus*) population they were studying between 1990-1992 along coastal regions of the Mediterranean Sea. This work also found that the major disorder associated with these infections are non-suppurative meningoencephalitis, which can cause major neurological damage to the central nervous system. Central nervous system damage affects the ability of the cetacean to navigate, in turn, leading to these mass cetacean stranding events (Van Bressem, 2007).

Parasitic worms such as *Nasitrema* tend to infect cranial sinuses of small odontocetes ultimately entering their brains (Geraci *et al.*, 1987). Once these infestations reach the brain, major neurological functions involved with navigation may weaken and deteriorate, possibly causing strandings and death in selected populations. Another parasite widely suggested, to contribute to stranding occurrences by disabling echolocation, is *Stenums* sp,. A pseudaliid, that usually inhabits the cranial sinuses of some whales and dolphins. (Geraci *et al.*, 1987). Additionally, toxins produced by marine algae may accumulate in fish and invertebrate assemblages and be fatal to predating cetaceans. For example, more than a dozen humpback whales died and stranded on Cape Cod in 1987 following the consumption of fish contaminated with saxitoxin, a paralytic neurotoxin (Geraci *et al.*, 2005). Geraci *et al.*, (2005) expressed that chronic exposure to saxitoxin may impair diving and foraging efforts which in turn could lead to increased strandings. Though the loss of sonar as a result of parasitic

infestation explains some cases, parasites are common in wild species and their presence is not always problematic (Walsh *et al*., 1990).

TABLE 1. Parasites from stranded cetaceans

Host	No. Examined	Parasite	U.S.N.M.[2] No.	Organ infected	No. infected	Percent infected
Phocoena phocoena	4					
		Hadwenius mironovi	74672	stomach, duodenum	1	25.0
		H. nipponicus	74673	stomach, duodenum	2	50.0
		Campula oblonga	74674	bile/pancreatic duct	4	100.0
		Halocercus invaginatus	74682	lung	3	75.0
		Pharurus convolutus	74683	lung	2	50.0
		Stenurus minor	74684	air sinus	3	75.0
		Anisakis simplex	74678	stomach	2	50.0
		Crassicauda sp.	74686	blubber, mammary	3	75.0
		Bolbosoma sp.	74685	intestine	1	25.0
Stenella coeruleoalba	2					
		Phyllobothrium delphini	74663	blubber	2	100.0
		Monorygma grimaldii	74667	mesentery	2	100.0
		Tetrabothrius forsteri	74666	duodenum	1	50.0
		Strobilocephalus triangularis	74662	colon	1	50.0
		Sarcocystis		muscle	1	50.0
Delphinus delphis	1					
		Phyllobothrium delphini		blubber	1	100.0
		Monorygma grimaldii		mesentery	1	100.0
Grampus griseus	1					
		Monorygma grimaldii		mesentery	1	100.0
		Crassicauda grampicola	74687	air sinus	1	100.0
		Penella sp.	74668	skin	1	100.0
Eschrichtius robustus	2					
		Cyamus ceti	74669	skin	2	100.0

[2]United States National Museum Parasite Reference Collection, Beltsville, Md.

Table 1. Parasites found in ten stranded cetacean species off the coast of Oregon between 1973- 1977 (Dailey *et al.*, 1978).

Methods

Stranding Data

Data was obtained for review from Mendy Garron, Northeast Regional Stranding Coordinator, with the National Marine Fisheries Services (NMFS) in Gloucester, MA. This data included mass strandings reported along the coastline of the northeastern United States from 1988-2006. The Protected Resources Department within NMFS has granted permission for the use of all information obtained through the Northeast Regional database. The data used in this study was compiled to represent each individual entry as one event; defined as any stranding of two or more marine mammals at the same location and similar time. Latitude and longitude measurements were included for 640 individual stranding occurrences, which were plotted using Global Mapper software (version 7, Global Mapper, LLC) to allow for visual imagery of the stranding data (Figure 1 and 2). Any entries without latitude and longitude measurements were excluded from the site mapping. Microsoft Excel (2007, original version 12.0.4518.1014) was used to do statistical analysis and graphing of trends or other data.

Geographical Data

Stranding events were also analyzed to determine geographical trends within the northeastern U.S. region, including strandings from Delaware, Maine, Massachusetts, New Jersey, Rhode Island, and Virginia. Additionally, research has been conducted to evaluate stranding frequencies within the five major coastline counties in Massachusetts including Barnstable, Nantucket, Essex, Suffolk, and Bristol. The number of events occurring in each northeastern state and the Massachusetts counties were counted and divided over the entire dataset from 1988-2006. All events with which longitude and latitudes were unknown were classified as "unknown region."

The data represent the total percentile of individual stranding events that occurred over the entire seventeen-year study. The states that experienced the most frequent strandings were re-examined to determine if there were dominant geographical influences. Massachusetts had the highest percentile of mass stranding events; as a

result, the state's topography was investigated to determine possible links between location and stranding events.

Seasonal Data

Stranding events were analyzed for seasonal trends. Relevant trends were investigated in both the northeastern region of the United States in its entirety and Massachusetts individually.

A seasonal index was created for each separate analysis of the data. A seasonal index estimates how the data vary from season to season over a discrete calendar year. The dataset was reviewed and each stranding event was separated into months, then counted and categorized into seasons to explore relationship trends. For these seasonal analyses, December through February represented the winter season; March through May represented the spring; June through August represented the summer; and September through November represented autumn. Each year was combined throughout the entire dataset and analyzed per season and then averaged for all 17 years (1988-2006). The average-percentage method was used, meaning the combined data for each season is expressed as a percentage for all 17 years.

The most frequently stranded species were identified and analyzed for comparison against seasonal trends. As the Atlantic white-sided dolphin (*Lagenorhynchus acutus)*, is the only species that exceed a threshold of $\geq$25% of the study population, it was determined that this species will be further investigated to determine seasonality and stranding correlations..

Species Data

Stranding occurrences were equally examined, to determine whether there were elevated trends in particular stranded species. Each listed animal in the dataset from 1988-2006 were counted, noted and grouped into species classifications for further assessments. There were eleven species identified and one animal was unidentified. The three major stranded species were short-beaked common dolphin *Delphinus delphis,* long-finned pilot whale *Globicephala melas,* and Atlantic white-sided dolphin.

Of the 11 species identified, *L. acutus* had the highest stranding occurrences. Therefore, this species was further analyzed to determine any biological factors that contribute to the increased strandings in the northeastern United States.

Annual Stranding Data

Stranding events were evaluated to determine the amount of mass stranding events that occurred annually during the 17-year period from 1988-2006. The total stranding incidents recorded in this dataset were calculated & categorized by combining the number of all stranded marine mammal species, to acquire a total on a yearly base between 1988 – 2006. Two years in 1989 and 1996 were excluded from the overall data analysis, as only a single stranding event was documented within those years.

Within the 17 years of the study period, the highest overall mass stranding occurrences (i.e., 10 or more) were analyzed to determine what abiotic factors potentially increased these events. Any year in which more than 90 individual strandings were recorded, the data was re-evaluated to determine if there was a correlation between the total amount of strandings and climactic changes observed regionally.

Results

All cetacean mass stranding events are displayed in Table 2. The chronological date of the stranding event, number of animals involved, species name, and site location is also provided for each event.

Geographical Data

The percentage of mass stranding events (single stranding events were excluded) occurring in separate geographical locations in the northeastern region of the United States from 1988-2006 (Figure 5). The chart is divided into six states and one unidentified area to include the total individual species stranded per mass stranding event. Of the seven areas, Massachusetts had the highest percentage of mass stranding events recorded; totaling 637 stranded species which represented 93% of the total stranded

population being reviewed for this study from 1988-2006. Virginia reported 24 individual stranded species, which accounts for 3.5% of the stranded species population in this study from 1988-2006 in the northeastern United States. Maine had eight recorded strandings, totaling 1% of the total mass stranding occurrences from the study period. Delaware closely ranked with Maine, with seven strandings recorded, equaling 1% of the total strandings recorded in the study region. Rhode Island documented five total strandings which represents 0.73% of the total stranding events over the same time period.

Of the unidentified areas, there were four reported individual strandings, which represent 0.58% of the total mass strandings reported in the northeastern United States. Lastly, New Jersey encompassed 0.29% of the total mass stranding events occurring in the northeastern region from 1988–2006, with only two individual strandings identified for a single event.

As identified throughout this review the highest density of recorded strandings occurred in Massachusetts from 1988-2006 as displayed in Figure 6. This chart is divided into stranding event in five counties within Massachusetts, including Barnstable, Nantucket, Essex, Suffolk and Bristol. Of the five counties, Barnstable had the highest percentage of mass stranding events recorded, which could be attributed to the county having the largest proportion of the Massachusetts shoreline. There were a total of 616 individually stranded species representing 97% of the stranded species found in Massachusetts from 1988-2006. Nantucket reported 14 individual stranded species totaling 2% of the stranded species over the 17-year study period. Lastly, Essex, Suffolk and Bristol counties had five individual strandings, equaling 1% of the total mass stranding occurrences.

Event Number	Date	Number of Animals	Species	Location
1	2/4/1988	3	*Delphinus delphis*	MA
2	4/29/1988	3	*Lagenorhynchus acutus*	MA
3	2/2/1990	2	*Lagenorhynchus acutus*	MA
4	2/15/1991	2	*Lagenorhynchus acutus*	MA
5	1/24/1992	3	*Various*	MA
6	8/27/1992	2	*Lagenorhynchus acutus*	MA
7	12/5/1992	2	*Delphinus delphis*	MA
8	12/9/1992	2	*Delphinus delphis*	MA
9	12/12/1992	20	*Globicephala melas*	MA
10	1/1/1993	3	*Delphinus delphis*	MA
11	4/6/1993	8	*Lagenorhynchus acutus*	MA
12	4/26/1993	2	*Phocoena phocoena*	VA
13	5/23/1993	2	*Phocoena phocoena*	VA
14	11/20/1993	5	*Grampus griseus*	MA
15	3/5/1994	3	*Delphinus delphis*	MA
16	3/14/1994	6	*Lagenorhynchus acutus*	MA
17	10/9/1994	2	*Lagenorhynchus acutus*	MA
18	5/8/1995	2	*Lagenorhynchus acutus*	MA
19	9/15/1997	3	*Delphinus delphis*	MA
20	9/16/1997	7	*Delphinus delphis*	MA
21	1/29/1998	27	*Lagenorhynchus acutus*	M
22	1/31/1998	47	*Lagenorhynchus acutus*	MA
23	2/1/1998	5	*Lagenorhynchus acutus*	MA
24	2/3/1998	3	*Various*	MA
25	2/4/1998	3	*Delphinus delphis*	MA
26	2/7/1998	5	*Lagenorhynchus acutus*	MA
27	2/18/1998	3	*Lagenorhynchus acutus*	MA
28	11/27/1998	4	*Lagenorhynchus acutus*	MA
29	2/3/1999	2	*Phocoena phocoena*	MA
30	2/19/1999	2	*Phocoena phocoena*	MA
31	3/7/1999	6	*Lagenorhynchus acutus*	MA
32	3/19/1999	29	*Lagenorhynchus acutus*	MA
33	3/20/1999	12	*Lagenorhynchus acutus*	MA
34	3/21/1999	2	*Lagenorhynchus acutus*	MA
35	3/22/1999	2	*Lagenorhynchus acutus*	MA
36	6/27/1999	2	*Globicephala melas*	MA
37	12/15/1999	3	*Delphinus delphis*	MA
38	4/11/2000	2	*Lagenorhynchus acutus*	MA
39	7/4/2000	11	*Globicephala melas*	MA
40	8/14/2000	2	*Lagenorhynchus acutus*	MA
41	8/26/2000	6	*Lagenorhynchus acutus*	MA
42	8/27/2000	5	*Lagenorhynchus acutus*	MA
43	4/13/2001	6	*Lagenorhynchus acutus*	MA
44	1/27/2002	9	*Delphinus delphis*	MA
45	3/5/2002	11	*Lagenorhynchus acutus*	MA

Event Number	Date	Number of Animals	*Species*	Location
46	3/6/2002	5	*Lagenorhynchus acutus*	MA
47	3/16/2002	6	*Lagenorhynchus acutus*	MA
48	3/27/2002	3	*Phocoena phocoena*	MA
49	4/10/2002	2	*Grampus griseus*	MA
50	5/24/2002	2	*Lagenorhynchus acutus*	MA
51	7/28/2002	14	*Steno bredanensis*	VA
52	7/29/2002	55	*Globicephala melas*	MA
53	8/31/2002	3	*Lagenorhynchus acutus*	MA
54	1/2/2003	4	*Lagenorhynchus acutus*	MA
55	2/18/2003	5	*Stenella coeruleoalba*	DE
56	3/21/2003	2	*Phocoena phocoena*	MA
57	4/11/2003	3	*Lagenorhynchus acutus*	MA
58	4/12/2003	2	*Lagenorhynchus acutus*	MA
59	4/13/2003	6	*Lagenorhynchus acutus*	MA
60	4/14/2003	10	*Lagenorhynchus acutus*	MA
61	4/15/2003	3	*Lagenorhynchus acutus*	MA
62	4/23/2003	3	*Lagenorhynchus acutus*	MA
63	7/28/2003	3	*Megaptera novaeangliae*	EZ
64	10/27/2003	8	*Grampus griseus*	MA
65	11/28/2003	4	*Lagenorhynchus acutus*	MA
66	4/3/2004	2	*Phocoena phocoena*	MA
67	6/10/2004	2	*Phocoena phocoena*	RI
68	7/16/2004	2	*Tursiops truncatus*	VA
69	11/14/2004	2	*Delphinus delphis*	MA
70	11/29/2004	3	*Delphinus delphis*	MA
71	11/30/2004	3	*Delphinus delphis*	MA
72	1/15/2005	7	*Delphinus delphis*	MA
73	1/19/2005	2	*Delphinus delphis*	MA
74	2/15/2005	13	*Lagenorhynchus acutus*	MA
75	2/17/2005	2	*Phocoena phocoena*	MA
76	4/17/2005	6	*Lagenorhynchus acutus*	MA
77	5/7/2005	2	*Lagenorhynchus acutus*	MA
78	5/8/2005	4	*Lagenorhynchus acutus*	MA
79	6/1/2005	2	*Phocoena phocoena*	MA
80	10/19/2005	6	*Delphinus delphis*	MA
81	12/10/2005	35	*Various*	MA
82	12/11/2005	2	*Globicephala melas*	MA
83	12/14/2005	3	*Globicephala melas*	MA
84	12/16/2005	3	*Delphinus delphis*	MA
85	12/30/2005	5	*Delphinus delphis*	MA
86	1/14/2006	10	*Delphinus delphis*	MA
87	1/17/2006	4	*Lagenorhynchus acutus*	MA
88	1/19/2006	16	*Various*	MA
89	1/21/2006	5	*Delphinus delphis*	MA
90	1/23/2006	4	*Various*	MA

Event Number	Date	Number of Animals	Species	Location
91	1/26/2006	4	*Delphinus delphis*	MA
92	1/27/2006	17	*Various*	MA
93	1/28/2006	5	*Lagenorhynchus acutus*	MA
94	2/1/2006	9	*Delphinus delphis*	MA
95	2/4/2006	8	*Various*	MA
96	2/23/2006	2	*Delphinus delphis*	MA
97	3/9/2006	3	*Delphinus delphis*	MA
98	7/17/2006	2	*Lagenorhynchus acutus*	MA
99	7/18/2006	6	*Lagenorhynchus acutus*	MA

Table 2. Mass stranding events in the Northeastern United States 1988-2006.

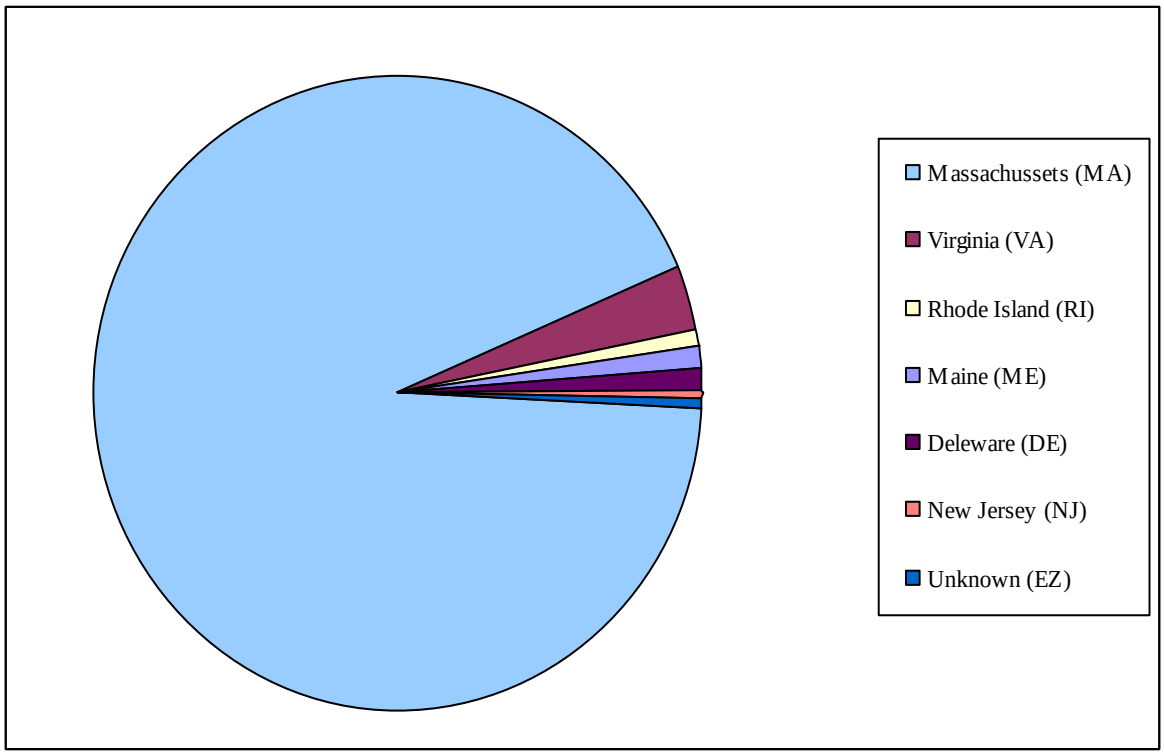


Figure 5. Total percentage of mass strandings events throughout the northeast United States from 1988 -2006.

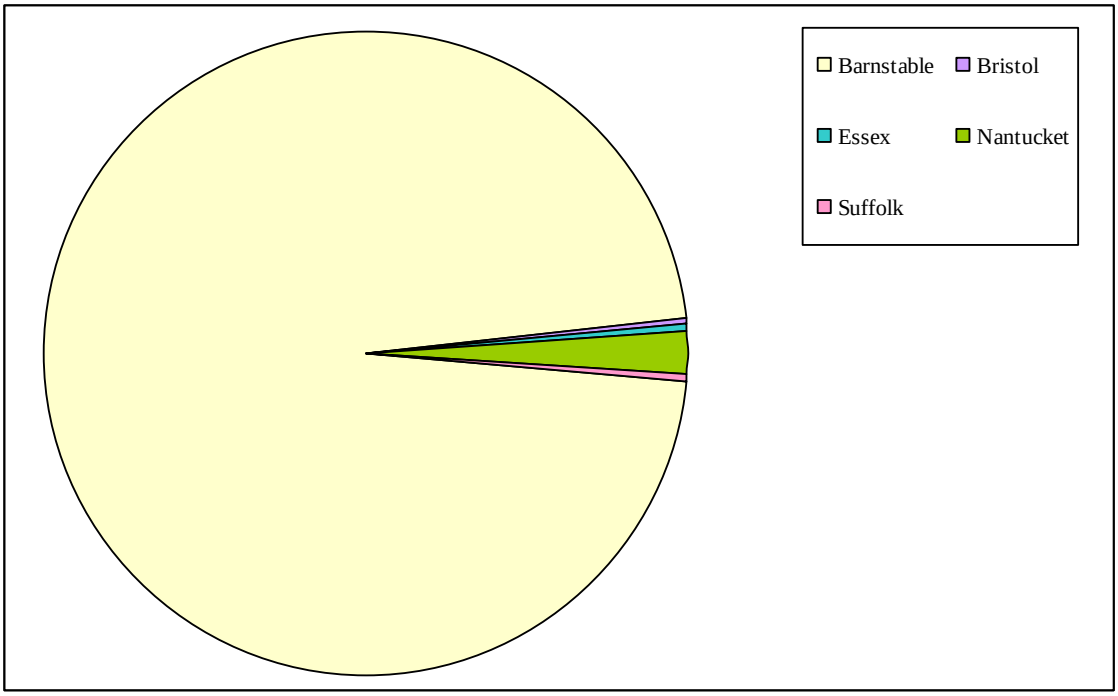


Figure 6. Total percentage of mass strandings events along the coastal counties of Massachusetts from 1988 -2006.

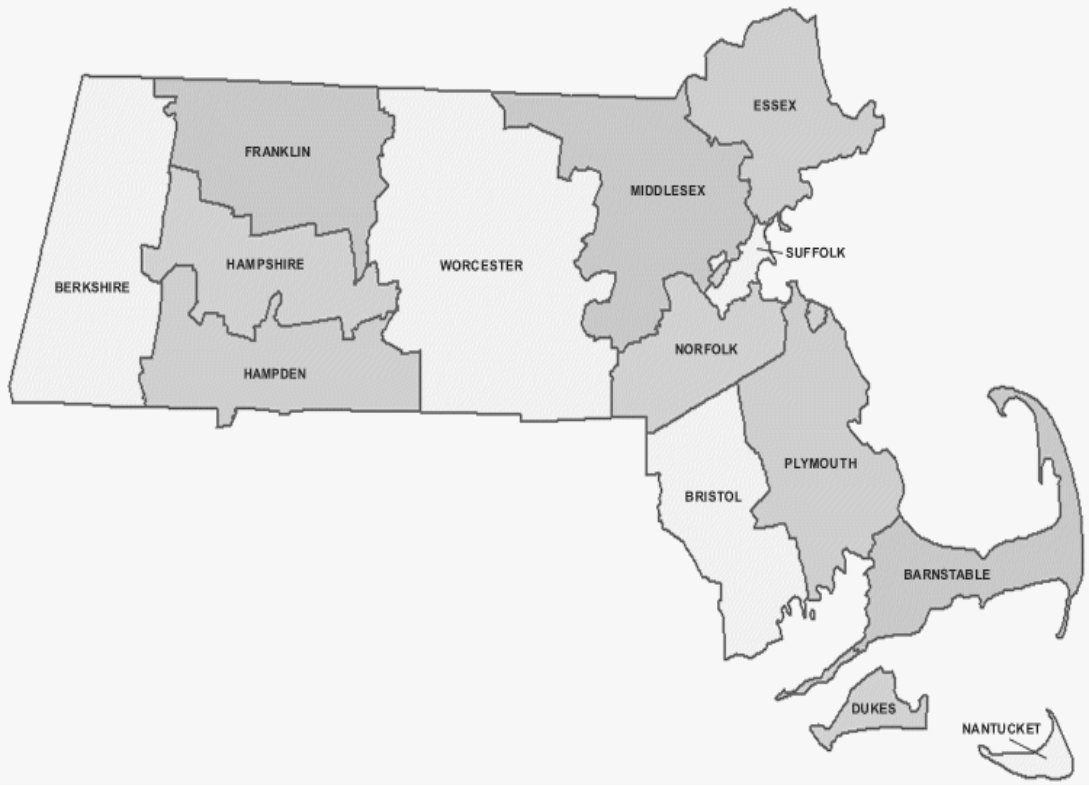


Figure 7. Map of the 14 counties located in the state of Massachusetts.

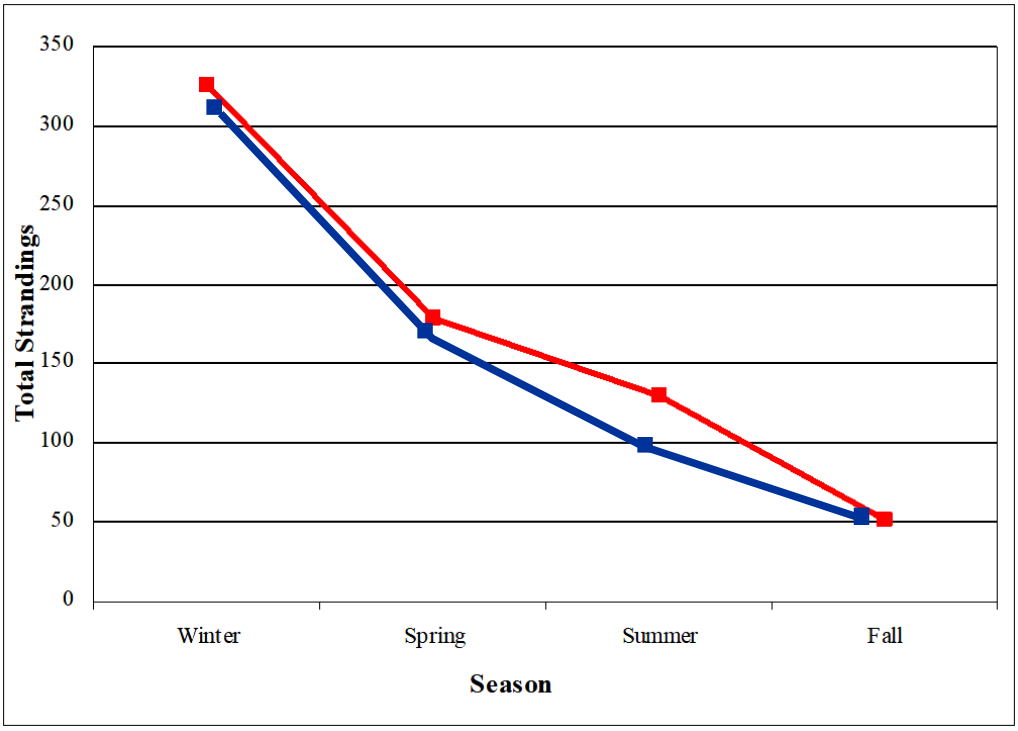
Seasonal Data

The total number of strandings per season by species in the northeast United States from 1988-2006 are displayed in Figure 8. The stranding totals were divided into winter, spring, summer, and fall seasons. The highest number of individually recorded stranding event occurred during the winter, from December to February. There were a total of 326 individually recorded strandings by identified species during the winter months of the 17-year study period. Within those months, there were a total of 38 mass stranding events. The second highest stranding season occurred during the spring, during the months of March and May. A total of 179 individual strandings and 31 mass stranding events were recorded during this season in the northeastern United States. During the summer months from June-August, there were 130 individual strandings reported. Each individual stranding occurred within one of the 15 mass stranding events during this time frame. The fewest mass stranding events occurred during the fall, between September and November. There were only 52 individual species strandings recorded during this season over a 17-year period.

In Massachusetts, the total individual species strandings per season are displayed in Figure 9. The highest number of individually recorded strandings occurred during the winter from December to February. There were a total of 317 species recorded during the winter months from 1988-2006. This represents 50% of all the stranding events along the Massachusetts coastline occurring during the winter seasons. The season with the second highest stranding count season was during the spring from March - May. A total of 169 individual strandings were recorded during this season, totaling 27% of all the stranding events in Massachusetts during the 17-year study period. During the summer months of June-August, there were 98 individual species recorded. A total of 15% of stranding events take place during the summer in Massachusetts. The lowest number of individual stranded species occurred during the fall between September-November. There were only 52 individual species recorded during the fall season, equaling 8% of the stranding events recorded in Massachusetts

Species Data

There were a total of 12 species that were identifiable from the dataset provided from the northeastern United States starting in 1988-2006. The species with the highest recorded strandings total was *L.acutus* (Figure 10). These Atlantic white-nosed dolphins accounted for 325 of the 687 total marine mammals stranded in the region, totaling 47.3% of the total species stranded. The species with the lowest amount of strandings were one "unidentifiable" species and the *w*hite-beaked dolphin. These two species totaled 0.003% of all species strandings during the 17-year study period. The short-beaked common dolphin *Delphinus delphis* accounted for 170 strandings; long-finned pilot whale *Globicephala melas* represented 112 strandings; harbor porpoise *Phocoena phocoena* included 23 strandings; Risso's dolphin *Grampus griseus* totaled 15 strandings; rough-toothed dolphin *Steno bredanensis* accounted for 14 strandings; harbor seal *Phoca vitulina* represented 12 strandings; striped dolphin *Stenella coeruleoalba* included six strandings; and common bottlenose dolphin *Tursiops truncates* totaled five strandings total. These species combined represented 52.4% of the total recorded marine mammal species recorded from 1988-2006.



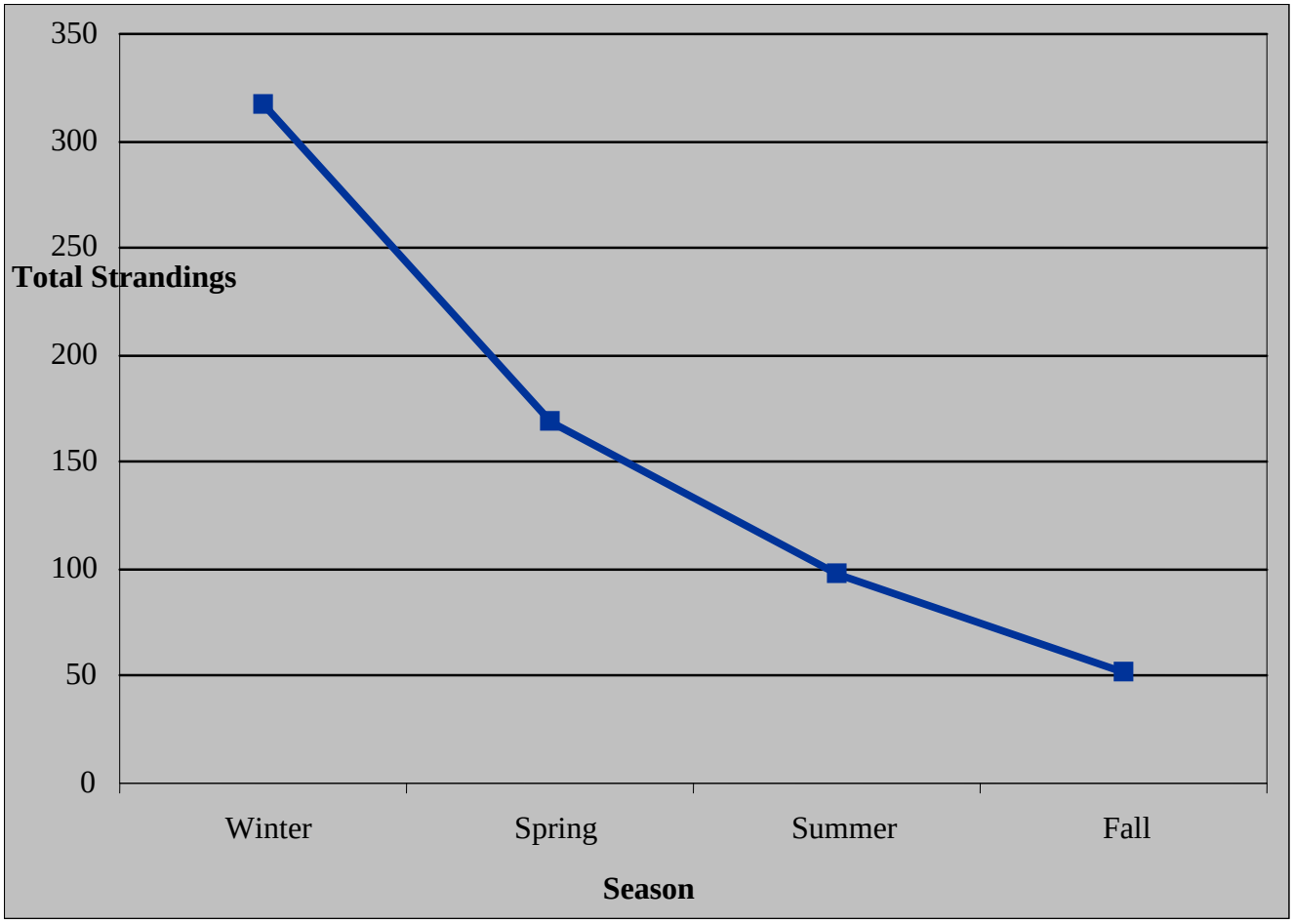
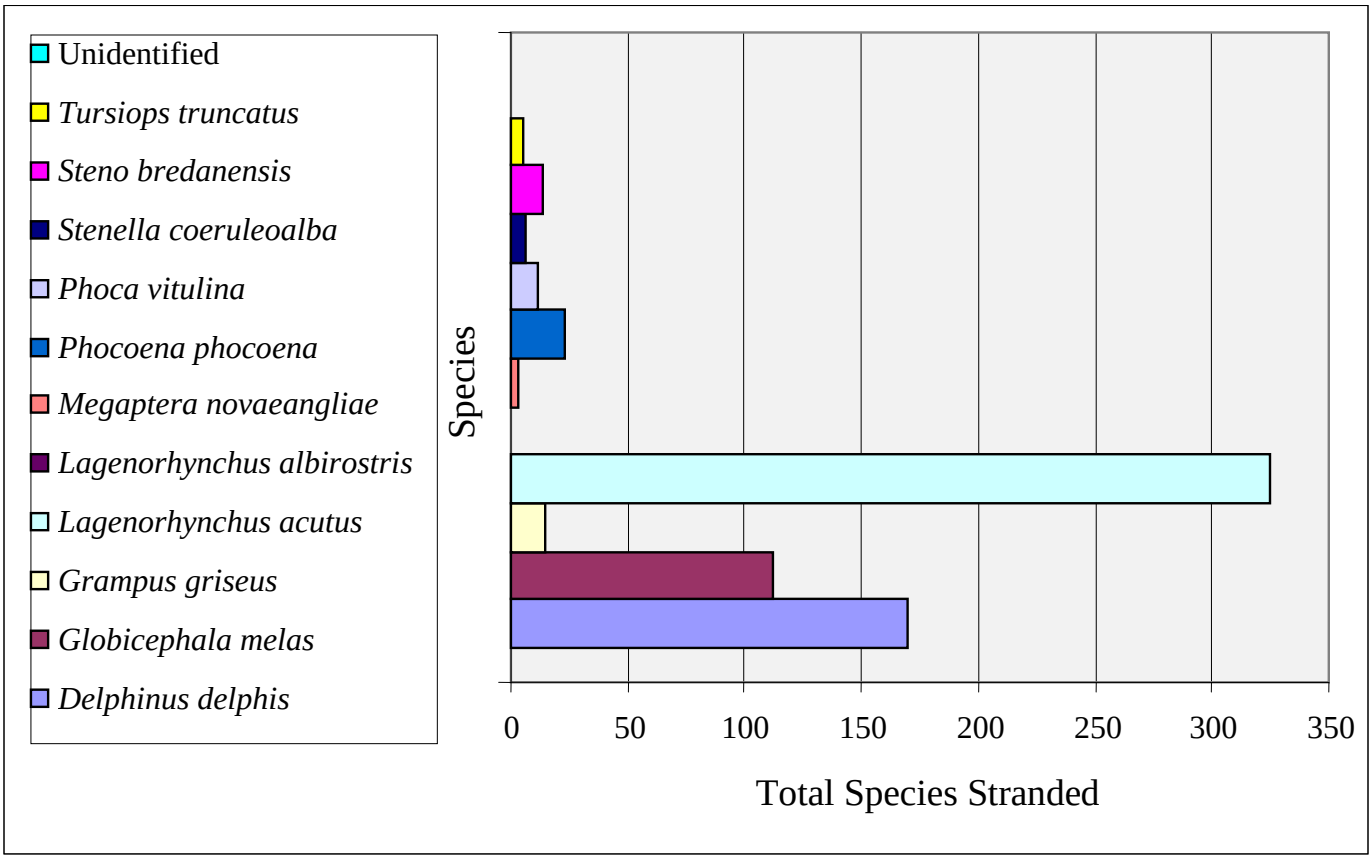


Figure 9. Seasonal index for all mass stranding data in Massachusetts from 1988 – 2006.



Total species stranded in the Northeast United States from 1988- 2006.

The seven individual species identified in Massachusetts as stranding during the 17-year study period are included in Figure 11. The white-beaked dolphin had the highest recorded species recorded for strandings and accounted for 323 of the 636 total marine mammals stranded along the Massachusetts coastline. Collectively, these seven species equal 50.8% of the state's total species-specific strandings and 47% of the overall total for the region from the 1988-2006 study period. The species with the lowest recorded strandings events were *Grampus griseus, Lagenorhynchus albirostris, Phocoena phocoena and Stenella coeruleoalba*. These four species comprised of 5% of all species strandings documented in Massachusetts over the 17-year period. *Delphinus delphis* accounted for 170 strandings and *Globicephala melas* represented 111 of 636 strandings. These two species combined embody 44.2% of the total recorded cetacean species stranded in Massachusetts from 1988-2006. *Delphinus delphis* accounts for

100% of this specific species stranded in the region and *G. melas* represents 99.1% of the *Globicephala* species identified in the region.

Species versus Seasonal Data

Figure 8 shows the total number of species stranded in the northeastern sector during the winter, spring, summer, and fall seasons. As projected, in Figure 10, *Lagenorhynchus acutus* was identified as the species with the highest total strandings in the region. Figure 12 shows that *L. acutus* also stranded more frequently during the winter and spring months. There were a total of 135 species recorded in the winter and 152 during the spring. The species with the second highest overall stranding rate, as displayed in Figure 6, were *Delphinus delphis*. These species stranding rates were most elevated during the winter and fall. *D. delphis* had a total of 135 recorded strandings during the winter and 23 stranding during the fall. With the remaining species including *Globicephala melas, Megaptera novaeangliae, Steno bredanensis,* and *Tursiops truncatus;* the total recorded strandings were below 115 per species. Amongst these four identified species the data reflects a consistent trend in summer seasonal stranding events between 1988–2006.

Annual Stranding Data

The total number of individual species strandings that occurred in the northeastern region of the United States from 1988–2006 is shown in Figure 13. The chart is divided across 17 years, with 1989 and 1996 excluded due to only a single stranding being recorded. Over the 17-year period, 2002 had the highest record of overall individual strandings. There were a total of 119 strandings recorded, equaling 17% of the total strandings from 1988-2006. Of those 119 stranded marine mammals, the populations consisted solely of two species; *Delphinus delphis* and *L. acutus*. The second highest year of recorded standings is 1998, which has 102 stranded animals, representing 15% of the stranded population. During 2005 and 2006 the total strandings recorded were relatively similar 96 $\pm$ 1 representing 14 % of the stranded population between 1988-2006. In 1999, there were 68 recorded marine mammal strandings across the

northeastern United States during the 17-year period of study. During this year, the total strandings made up 10% of the total strandings population. From 1988-1997 the total number of strandings recorded were fewer than or equal to 30 totaling 15% of all strandings documented. Between 1993–1994, the same total of 21 species were identified and recorded. From 1990-1991 the lowest total of strandings were recorded with two per year each being identified as *Lagenorhynchus acutus*. In 2000, 2001, 2003, and 2004 the total recorded strandings was fewer than 60 individuals averaging 9% of the overall strandings documented.

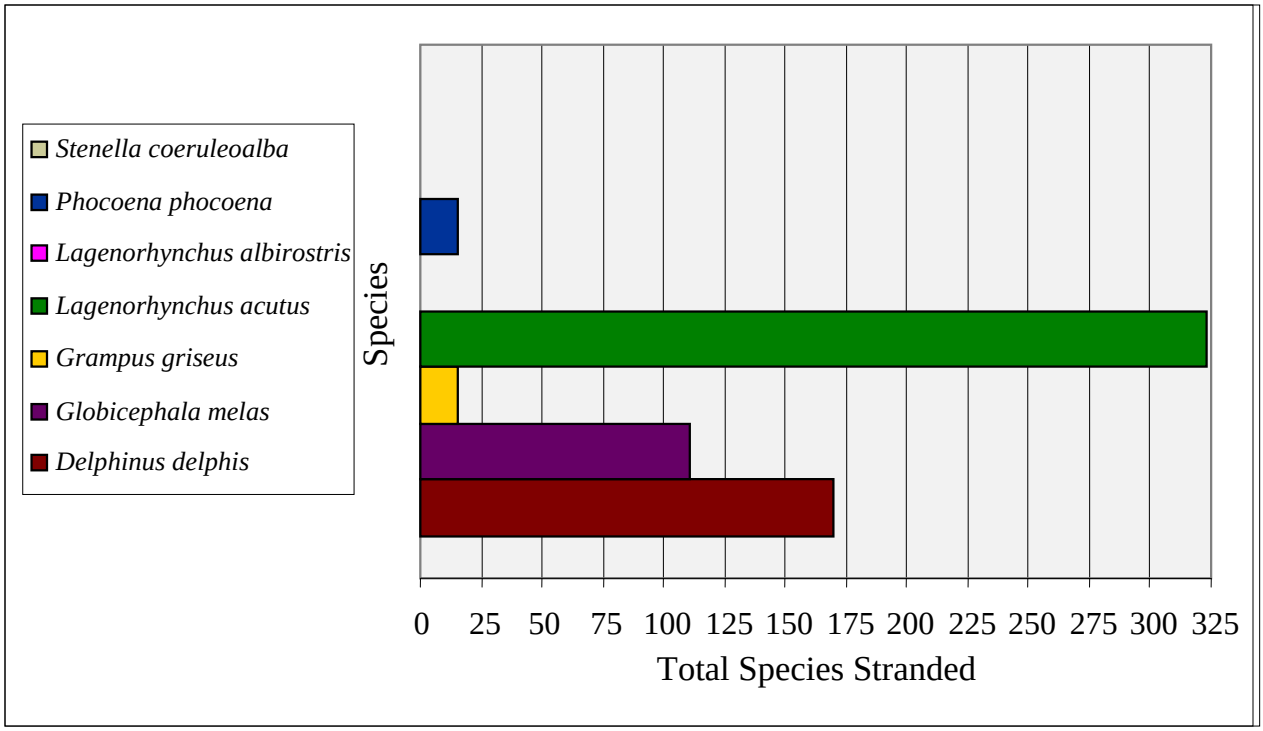


Figure 11. Total species stranded in Massachusetts from 1988- 2006.

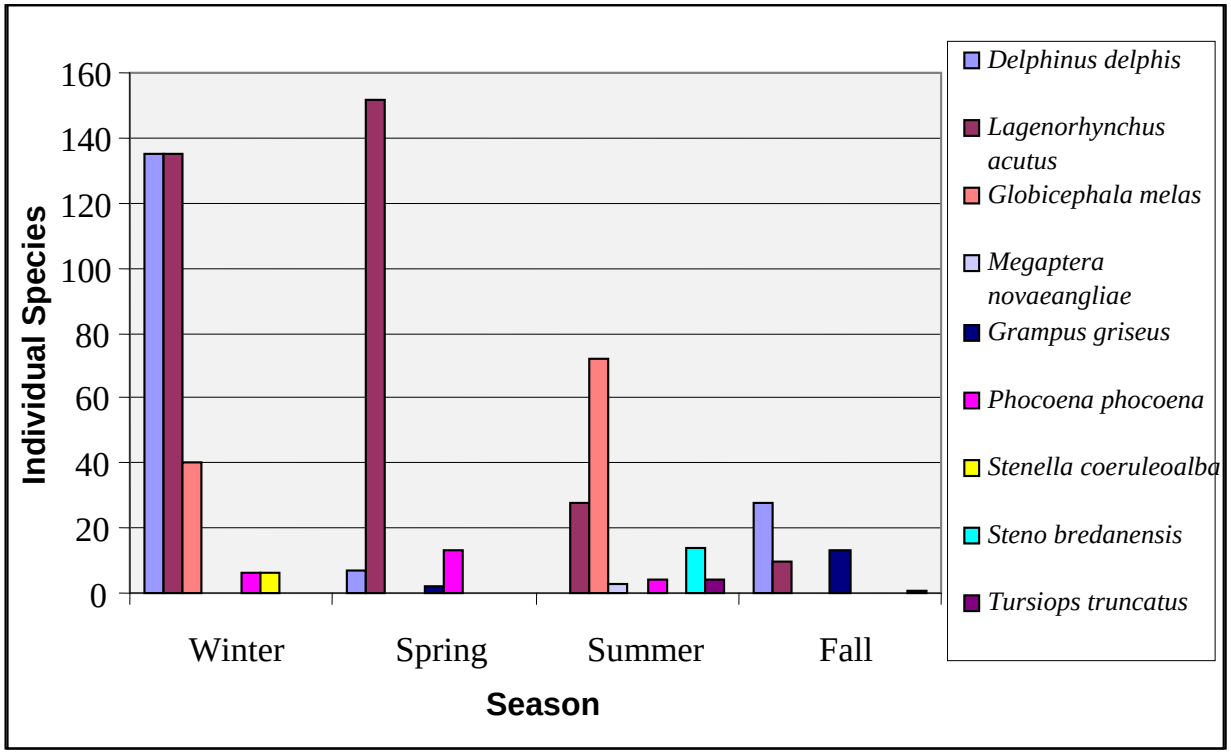


Figure 12. Seasonal index for mass stranding data separated by species stranded from 1988- 2006.

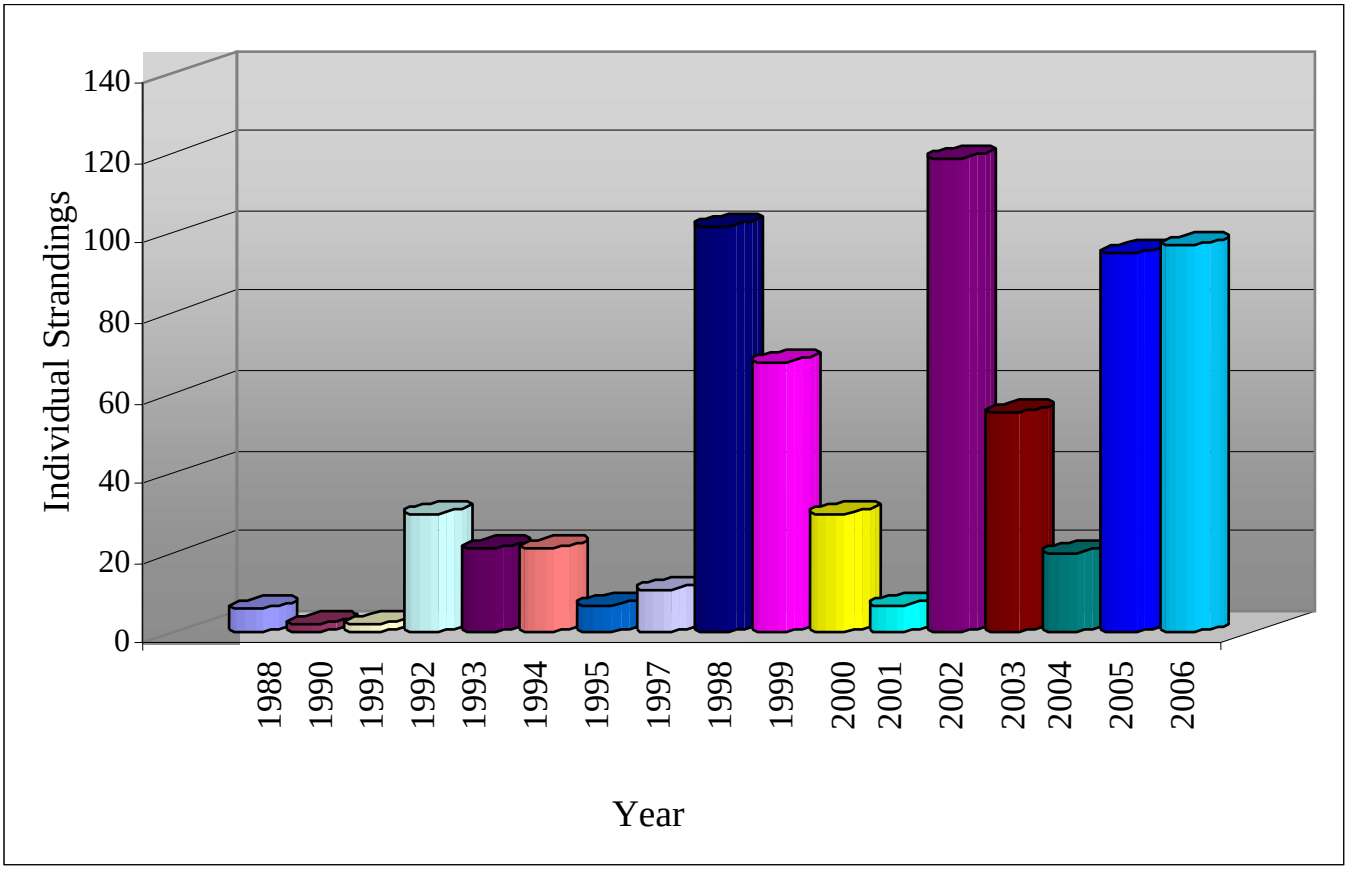
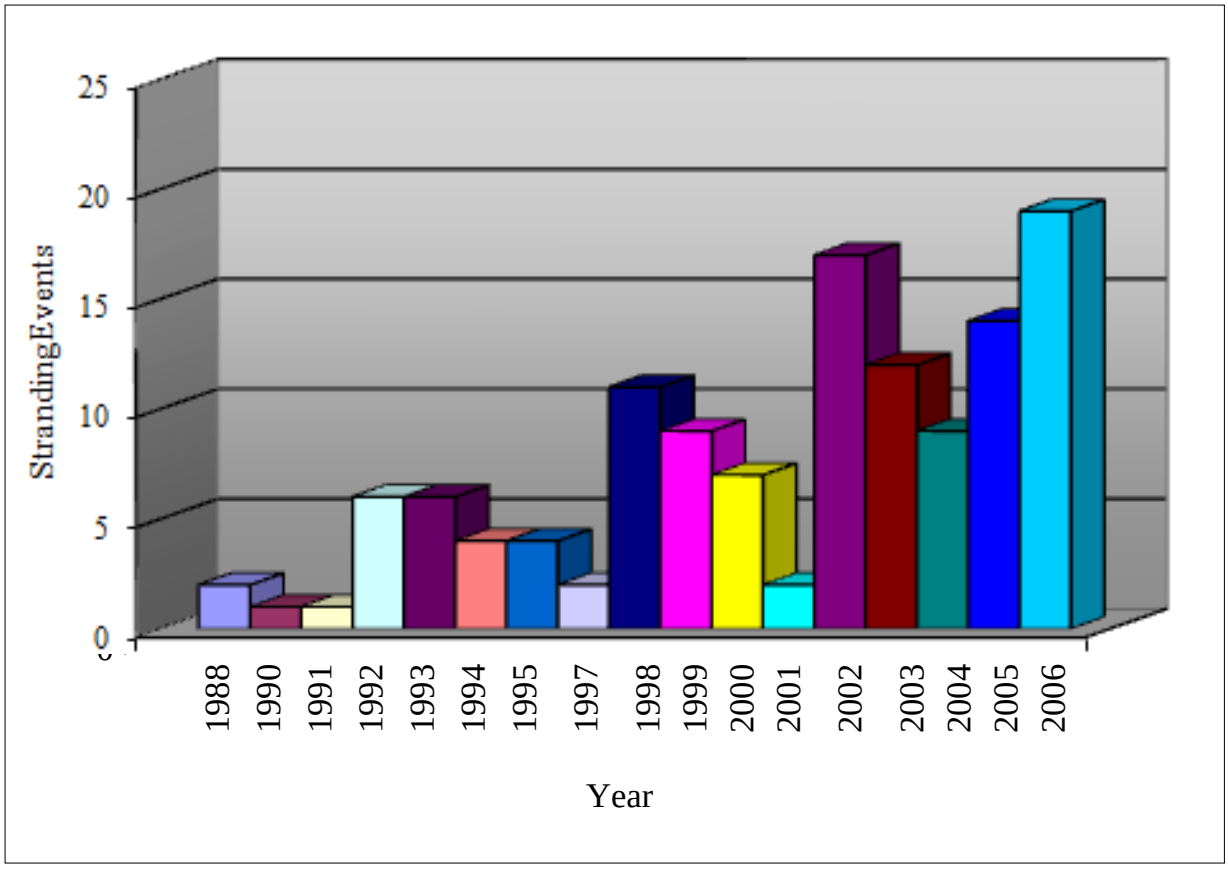


Figure 13. Total individual strandings per year in the northeast United States from 1988 – 2006.

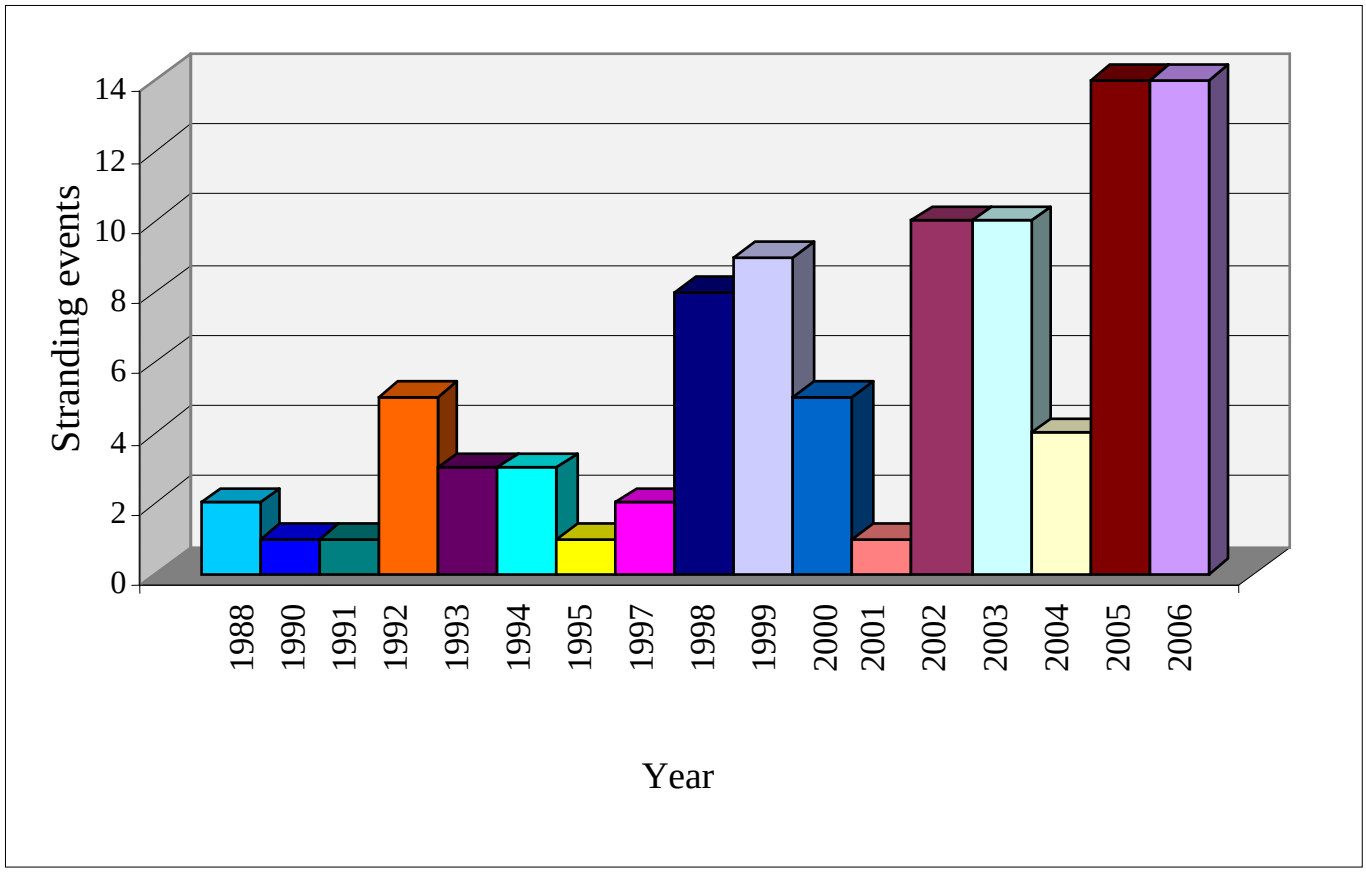
In Figure 14, each stranding event in the northeast region was calculated over a 17-year period of time. In this study an event is defined as all individual cetaceans stranded on the same date across the northeastern region. The highest total of mass stranding events was documented in 2006. There were 19 events recorded, totaling 15% of the mass strandings that occurred within the 17-year study. A total of 17 strandings were documented in 2002, which reflects the seconded highest number of stranding events during the study period. In 2003 and 2005, 12 events were documented each year, representing 10% of the total mass stranding events recorded during the study period. In 1998, 11 events were recorded within the regional northeastern United States. The following years including 1988-1997,

The years representing the highest percentage of mass stranding events (42%) during the study years were 1999-2001 and 2004. The lowest number of events recorded yearly during the study period transpired in 1990 and 1991, with only one mass stranding event each year.

The total stranding events recorded in Massachusetts from 1988-2006 is presented in Figure 15. The highest total of mass stranding events occurred in 2005 and 2006. Fourteen were recorded during this period, identifying that 30% of the region's mass strandings occurred in Massachusetts. In 2002 and 2003, the second highest number of stranding events occurred with a total of 10 documented. These events represent 22% of the mass strandings documented in the area. In 1999, a total of nine events were recorded and eight were documented in 1998. During these two combined years (1998 and 1999), 18% of Massachusetts' mass stranding events during the study period were observed. The remaining years including: 1988-1997, 2000-2001 and 2004 represented 30% of the total stranding events documented throughout Massachusetts. During these years the total stranding events equaled fewer than or equal to five annually. The fewest number of events documented was one in each of the following years: 1990, 1991, 1995, and 2001.



Total mass stranding events in the northeast United States from 1988 – 2006.



Total mass stranding events in Massachusetts from 1988 – 2006.

Discussion

Obtaining a developed understanding of why marine mammals strand has been a research focal point for centuries. Current and previous studies analyze potential contributing factors leading to the increase of single and mass stranding events globally. Though there are several explanations for the cause of stranding events, there is not yet a general consensus of one dominant factor causing stranding events to occur. However, the further identification of key factors leading to mass stranding events may be useful in facilitating the coordination and development of effective response efforts.

In this review of prior stranding events, the focus was to specifically assess the influence of biological and abiotic factors on cetacean mass stranding events in the coastal Northeastern United States. Several factors were identified as contributors leading to

mass stranding events, including coastal topography, oceanic circulatory patterns, seasonal changes, and biological infections or disease. The results confirm a geographic trend, with coastal topography as a major factor leading to mass stranding events in the northeastern United States. Specifically, Massachusetts was identified as having the highest recorded number of single and mass stranding events in the northeastern United States during the 1988-2006 study period. These results emphasize the correlation between strandings and coastal typography of the region (Mazzuca *et al.,* 1999). The Massachusetts' coastline in particular has gently sloping beaches, broad tidal flats, and extreme tidal flow during near full and new moons, along with adjacent protruding sections of the coastline (Thoreau, 1987). As concluded in research conducted by Kirschvink et. al (1986), this type of shoreline topography has proven to have an impact on increased cetacean stranding events, potentially due to the disruption of successful navigational tools, similar to echolocation. The identification of these physical factors, including wind and ocean circulation patterns in conjunction with the coastal typography of the region, has proven to intensify change within the oceanographic environment leading to stranding events. These results, serve as measurable identifiers to assist with proactively determining the location and timing of future stranding events (Van Bressem, 2007).

It is important to also note that these physical abiotic factors may not be the initial cause of mass strandings, but they could contribute to the seasonality and geographical distribution of these events. As well, biological issues have proven to be the most likely causes of mass strandings, and physical factors influence water chemistry, dexterity, etc., in turn can affect mammals' movement towards ocean coastline where cetaceans will typically strand.

The seasonal findings confirm correlations between peak standing occurrences and changes in meteorological seasons, as identified in the spring and winter.
These connections between seasons and increase stranding events support the concept that coastal versus offshore seasonal variations; and or the seasonal variability has a direct effect on oceanographic conditions influencing stranding occurrences (Walker *et. al.,* 2005). In combination with seasonal changes, which attributes to cool relatively fresh waters from the Gulf of Maine, these changes increase prey populations therefore altering

the cetacean migratory patterns and increasing stranding events (Reeves *et al*., 2002). Ultimately, data and results confirm the suggestion that environmental variances (e.g. seasonal changes) directly correlate with fluctuations in stranding numbers.

Geomagnetic Sensitivity

The question of how migratory species, navigate throughout their marine environment has been under examination for centuries. More specifically if stimuli, like geomagnetic fields, effect navigational ques used by migratory cetacean species when identifying migratory patterns. Walker et al. (1992), show that migratory species, Fin whales, do posses magnetic senses in which are used to forage migratory patterns towards areas of both low magnetic intensity and geomagnetic field gradients. Research conducted in the United States during the 1970s suggests that these animals possess sensory receptors capable of transmitting geomagnetic cues to the nervous system assisting them with geographical orientation (Kirschvink *et al*., 1986). Between 1983 and 1985, research efforts by Margaret Klinowaska (1986) concentrated on the correlation between cetacean strandings and geomagnetic disturbances in and around mass stranding sites internationally. Klinowaskas' (1986) research focused on cetacean species use of the Earth's magnetic field as a tool for navigation. Suggesting most stranding events were in areas where magnetic contours of the ocean floor were perpendicularly intersecting land, most importantly in areas of geomagnetic lows (Klinowaska, 1986). Klinowaska hypothesized that these animals misinterpret geomagnetic information causing them to strand ashore off the coastal United States. Her results shed light on the probability that the distribution and migration of certain stranded cetacean species could also be linked to the movement of prey.

Similarly, research conducted by Kirschvink *et al*. (1985) studied the correlation between cetacean strandings and geomagnetic sensitivity along the eastern coast of the United States. Under the premise that in order for cetacean species to utilize geomagnetic fields as tools of navigation, they must possess highly developed sensory receptors that can translate these cues; they hypothesized that cetaceans use anomalies in geomagnetic fields as navigational tools indirectly increasingly affecting their tendency to strand. Kirschvink *et al.* (1985) showed there were increased tendencies of stranding

events near areas with low magnetic intensity along the United States' continental margins. These results support my research efforts, with a plausible explanation suggesting abiotic factors including, bathymetric effects such as, high latitude areas with steep magnetic inclines, canyons and valleys penetrate through geological strata weaken geomagnetic fields and increasing the probability of mass stranding occurrences (Kirschvink *et al.,* 1985).

Although the analysis of geophysical and hydrological characteristics were not plotted or compared in this study, the referenced research efforts highlight and support the theory associating geomagnetic sensitivity in cetaceans and its effect on stranding events.. Moreover, the lack of extensive research findings suggest a stronger need for continued research to establish a more conclusive affiliation between geomagnetic sensitivity and the cause of cetacean mass stranding events. Geomagnetic sensitivities is one of many combined factors potentially leading to mass stranding events along the northeastern coastline of the United States.

Geographical Relevance

The highest number of recorded stranding events during the period of time reviewed here occurred along the coasts of Massachusetts, peaking during winter and spring months (December-May). Geographical relevance, particularly as it pertains to increased mass stranding events can be associated with changes in coastal topography and the landscaping of the area. Over time, some of these changes to the geographical landscape, similar to the state of Massachusetts, may be caused by climate change or direct human activity altering the coastal compositions, such as coastal dredging and beach erosion replenishment (Bjorge, 2001). These coastal alterations can affect sedimentation ultimately blocking traditional movement patterns of marine mammals that can lead to population fragmentation and navigational disorientation (Evans, 2002). Additionally, research results expressed by Charles Brown (1939) further confirm my findings, concluding that destructive and erosive factors observed along the coastline of the northeastern United States, cause elevated high tides and storm swells, jeopardizing the survival of animals whom have navigated along its coast.

Species Data in Relation to Seasonality

As the results confirm, the greatest abundance of species strandings within the northeastern United States between 1988 and 2006, were amongst *L. acutus* and *D. delphis*. This concentration could show a relationship between the increase of cooler temperatures and the decreased salinity of freshwater integrating into the Atlantic Ocean from the Gulf of Maine during peak stranding seasons (Selzer *et. al.,* 1988). The correlation is particularly relevant to *L. acutus* ,as their survival, in part, depends upon the temperate and sub-polar waters found within the northeastern Atlantic region (Weinrich *et al.,* 2001). Though the results herein for *L. acutus* strandings during the winter and spring seasons do not coincide with the U.S. Atlantic and Gulf of Mexico Marine Mammal stock assessments, as reported by the NMFS (Blaylock et. al., 1995, 1998, 2001). The study results do confirm the theory that abiotic factors including seasonality have a direct effect on total stranding occurrences. In contrast, the seasonal data results for *Delphinus delphis,* showing there was an increased frequency of species strandings during the winter is supported by the U.S. NMFS, U.S. Atlantic and Gulf of Mexico Marine Mammal stock assessment report (Baylock *et. al.,* 1995). This increased number of strandings during the winter could be attributed to the species being identified as a pelagic migrating species with increased densities off the northwestern Atlantic Ocean during the winter and summer due to increased forging opportunities, where the highest density of squid populations are present ((Selzer *et. al.,* 1988 and Geraci *et al.,* 2005).

Moreover, the summation of these results shows a significant difference between mass stranding events and normal seasonal changes. Increasing and decreasing stranding occurrences during the four seasons implies that stranding events can be a result of seasonal variances, possibly including abnormal temperatures and changes in metrological patterns. As there are continual changes in stranding numbers per season, seasonal variances are a supported correlate between the season and recorded stranding events.

Effects of Wind Conditions on Strandings

A change in wind forcing effects on ocean circulation has been noted as an important aspect of the ocean environment (Fiedler, 2002). Though it is highly unlikely that wind stress alone would cause a stranding to occur, the direction of wind affects the properties of water in that area. During this assessment and investigation, research on wind analysis relevant to the 17-year review period was not conducted. Despite the lack of wind data analysis for this study, there have been researchers whom have studied the connections wind have on ocean circulatory patterns which could possibly influence stranding events internationally.

A study by Walker *et al.* (2005) focused on environmental correlations of cetacean mass stranding in Florida. More specifically, the results from their wind data analysis of the southwestern region of Florida were similar to results found in locations like Massachusetts. It was noted that the areas of strandings within the study were geographically located close to capes, bays, or other irregularities in the coastline (Walker *et al.* 2005). The wind analysis portion of their research was conducted to determine the influence wind has on water mass characteristics. The inference between different water mass properties is associated with higher biological productivity which could affect cetacean distribution when foraging (Walker *et al.,* 2005). Their research analyzed mass stranding events between 1977 and 2001. The results determined that the seasons in which most strandings occurred on the southwest coast of Florida coincided with an increase in downwelling favorable winds. Coastline irregularities similar to the ones in southwest Florida and the northeast region of the United States ultimately complicate water flow causing wind force responses difficult to determine (Li and Weisberg, 1999). Therefore, wind blowing on the northeastern coast of the United States could cause different oceanographic effects due to the diverse coastline orientation. This could both increase or decrease cetacean population totals all year around.

Research conducted by Evans *et al.* (2005) focused on changes in weather patterns and its effects on cetacean stranding variability; specifically, their hypothesis linked the environmental links of changing wind pattern and stranding events. Their data analysis results, spanning from 1920-2002, show that the regional persistence of zonal winds were positively correlated to stranding events along the coastline of Australia.

Specifically, the variability in westerly and southerly winds seemed to be hemispheric and could be associated with the enhancement of higher northward Ekman transport of colder sub-Antarctic waters. With these increased Australian wind patterns shifting sea-level gradients, it is possible these changes caused an increase of nutrient rich waters resulting in a net migration of cetaceans following their prey (Evans *et al.*, 2005). This could lead to an increase in the number of cetacean species within the region, increasing the probability of strands.

Conclusion

The results of this analysis and literature review explored how abiotic factors including seasonal variance, wind patterns, coastal topography, as well as biological factors including parasitic infections can influence mass stranding events in the northeastern United States. The causes of cetacean mass stranding events still remain unclear and or uncertain. Though there has been extensive research conducted on single and mass stranding events including: biological, climactic, seasonal and geomagnetic investigations, few studies have provided tangible evidence that explains the correlations between environmental factors and stranding events. When researching the cause of stranding events, it is always good to generalize causes (Odell, 1987) because there may be more than one or the occurrence could simply be considered an accident. It is worth noting, that an identified general concurrence amongst many marine science professionals globally show that most stranded marine mammal, cetacean species are pelagic species, primarily a part of offshore migratory populations (Brabyn *et al.* (1992), Lopez *et al.* (1999), Mignucci-Giannoni *et al.* (1999), Nicol *et al.* (1988), Selzer *et. al.* (1988), Walker *et al.* (2005)).

Some scientists believe that single animal strandings are a consequence of disease and animals are brought to shore passively, while mass strandings occur more actively. Many factors may affect this higher likelihood: infectious diseases, seasonality, availability of prey, and wind patterns. The forced movement of water due to wind changes may affect where prey is located, as well as, the location and movement of frontal convergences. For those species found outside of the geographical area in which they are frequently associated, Selzer and Payne (1988) noted that this is a result of

fluctuations in food availability and oceanographic conditions. In this study it was concluded that some species in fact move farther inshore following migrations of their prey, but many studies have shown that cetaceans follow the frontal structure movements, rather than prey directly (Fiedler *et al*., 1997, Griffin 1997, Tynan 1997, Bjorge 2001, Forcada 2002). These frontal structure movements could be generated by warm-core eddy interactions with the Gulf of Maine shelf or coastline slopes. Bulk movement of water may also assist in pulling animals into shore as a result of passive movement (Geraci *et al.,* 1993). However, the location of frontal convergences may dictate where cetacean species are when they feed, and subsequent environmental changes may affect strandings which could be a combination of active and passive movement. All these events allow for species to be sited on and closer to the continental slope as a result of frontal system location. Therefore, bathymetry and wind induced water circulation are important factors in mass stranding events.

The physical abiotic factors, along with, biological factors were the core review of this review. It is important to note that these physical abiotic factors, including: climate change, wind and ocean circulation patterns may not be the initial cause of the stranding, but they contribute to the seasonality and geographical distribution of these recorded events. Biological issues, such as disease, parasitic infections, and other illness, tend to be most likely the more tangible causes of strandings. The most substantial amount of evidence supporting these claims comes from continued biological sampling conducted through necropsies by most marine stranding networks across the United States. In addition, these physical oceanographic factors as stated above, influence water and animal movement towards the coast. These factors do not directly cause the animals to strand, but they affect their movements and influence their shoreward migration, initiating the stranding event.

As previously mentioned, physical abiotic factors including, climate and seasonal changes were important as a possible correlate intensifying the occurrence of mass stranding events. In many studies a seasonal change is noted, but rarely discussed in further detail. Researchers such as Nicol and Croome (1988) found a peak in strandings in Tasmania's midsummer, attributing it to possible migration to feeding areas. Mignucci-Giannoni *et al.* (1999) noted that strandings in Puerto Rico and the Virgin Island are more common in the winter and spring, while Lopez *et al.* (1999) also noted a

winter/spring peak when analyzing data for the Galician Coast in northwest Spain. Duguy and Wisdorff (1988) noted a spring maximum strandings on the French Atlantic coast. However, Duguy and Wisdorff (1988) also found the seasonal fluctuations to be unrelated to meteorological factors. Strandings along the Dutch coast are related to the sea surface temperature and prey species availability, peaking in the summer and dropping in the winter (Bakker and Smeenk 1990). With more data from different areas of the world it could be determined whether migration, changes in habitat use, or weather patterns affect the seasonality of strandings.

In summary, it is obvious that there are a number of factors that must co-occur for a mass stranding to happen. It is important to continue to investigate the significance of these factors in other areas of the world where historical standing data and meteorological data exist. This will encourage and assist with further development of stranding management plans and accurate response protocols to reduce the number of fatal mass stranding occurrences along the coasts of the United States and worldwide.

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