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Temporal and Spatial Distribution of Cetacean Strandings Focusing On The Bottlenose Dolphin (Tursiops Truncatus) with a Synthesis of Potential Causes

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HALMOS COLLEGE OF NATURAL SCIENCES AND OCEANOGRAPHY

TEMPORAL AND SPATIAL DISTRIBUTION OF CETACEAN STRANDINGS FOCUSING ON THE BOTTLENOSE DOLPHIN (*TURSIOPS TRUNCATUS*) WITH A SYNTHESIS OF POTENTIAL CAUSES

By

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Abstract

A comprehensive review of the literature and a quantitative statistical analysis of that information are presented. A total of 6,015 cetaceans stranded at 36 locations from 24 peer reviewed articles published between 1999 and 2014 are documented, with the two most common stranding locations being the Canary Islands - accounting for 49 of the total cetacean stranding events - and Cape Cod - accounting for 31 of total cetacean stranding events. The documented cetacean stranding events included 805 for bottlenose dolphins (*Tursiops truncatus*) at a total of ten locations from 11 peer reviewed articles. When all single stranding events are eliminated and the collected data is analyzed, there are more documented stranding events of bottlenose dolphins than of any other cetacean species in the peer-reviewed literature. Using data collected from the Marine Mammal Stranding Network for the Southeast United States, a Chi-Square goodness of fit test is used to determine whether the number of bottlenose dolphin strandings is significantly different from the causes of strandings or causes of death categories. The analyses conclude that there is no significant difference among the categories of strandings or death. The general life history of the bottlenose dolphin is presented with special emphasis on its behavior and social structure, which are thought to affect stranding event frequencies. Various populations of bottlenose dolphins are also explored. The capstone concludes with a synopsis of speculated causes for stranding events and a synthesis discussion of stranding causes.

Keywords: Diseases, Immunosuppressants, Marine Debris, HABs, Parasites, Pollutants

Introduction

Marine mammal strandings occur all over the world (Bogomolni et al. 2010, 143; Lemos et al. 2013, 167). A mass stranding of marine mammals is defined as either when two or more cetaceans come ashore alive at the same time and place (Arbelo et al. 2013, 92; Cox et al. 2006, 177; Jepson et al. 2013; Mazzuca et al. 1999, 106; Weijs et al. 2013, 118), or when a part of the same group strands within one to three days after the first stranding (Mazzuca et al. 1999, 106). This definition excludes mother-calf pairs. Mass strandings can involve hundreds of individuals and in some cases, stranded pods often consist of a mix of live, apparently healthy individuals, with others ill or injured (105). They are also subject to removing 50 percent or more of a population (Young 1994, 414) and can be grossly under-reported (Knowltobn and Kraus 2001, 207). Due to the large size of cetaceans, the high group cohesion demonstrated by many of these species, and that cetacean behavior will be driven by the search for food, mass strandings of these species are considered common occurrences (Bradshaw et al. 2005, 585). For example, between 1977 and 2002, 70 live-stranded odontocetes or toothed whales of 13 species stranded off the coast of California (Zagzebski et al. 2006, 336). Males had been observed to mass strand more often than females (Promislow 1991, 1875; Zagzebski et al. 2006, 341), which may reflect sex differences in social structure and foraging behavior of California cetaceans (Zagzebski et al. 2006, 341). It may also be that males are more susceptible to the causes of strandings such as infectious diseases and trauma (341).

According to reviews by Jepson et al. 2013 and Mazzuca et al. 1999 (106), at least 19 species of cetaceans have been known to mass strand, as documented in Table 1. Some species that commonly strand include the false killer whale (*Pseudorca crassidens*), long-finned pilot whale (*Globicephala melas*), short-finned pilot whale (*Globicephala macrorhynchus*), Atlantic white-sided dolphin (*Lagenorhynchus acutus*), and white-beaked dolphin (*Lagenorhynchus albirostris*) (Jepson et al. 2013). Strandings of bottlenose dolphins along the United States Atlantic Coast have been observed since the late 1800s (McLellan et al. 2002, 297). These cetaceans are all pelagic odontocetes with a highly evolved social structure, which are characteristics usually observed in mass stranded pods (Jepson et al. 2013). Single and mass strandings of these odontocete species have increased with the increasing human population along the coasts (Zagzebski et al. 2006, 334).

This capstone provides information on the various causes of or factors in stranding events of a particular species of cetacean, the bottlenose dolphin. After a quantitative review of the researched literature, it was determined that there were more stranding events reported involving bottlenose dolphins than any other cetacean species. The life history and behavior of the bottlenose dolphin is explored, as well as information on the reasons for mass strandings, including temporal and spatial information. Statistical analysis is conducted on information gathered from the literature on the causes of bottlenose dolphin strandings. This capstone also discusses a review of the factors in or causes of these dolphin strandings, and includes information on diseases and parasites, persistent organic pollutants (POPs) such as organochlorines, heavy metals and trace elements, marine debris, and harmful algal blooms (HABs). The conclusion presents a synopsis of the potential causes of bottlenose dolphin stranding events.

Methods

Over one hundred peer-reviewed journal articles dealing with cetacean strandings were read and information was synthesized and organized, producing one table (Table 1) listing mass strandings of various cetacean species. The table was interpreted for further information regarding cetacean strandings.

Data on the causes of bottlenose dolphin strandings were obtained from the Florida Fish and Wildlife Conservation Commission (FWC) office in Jacksonville, FL as well as from the peer-reviewed article McFee and Lipscomb (2009). Both data sets were analyzed using a Chi-Square goodness of fit test with a 0.05 level of significance to determine whether the strandings of bottlenose dolphins were significantly different among the causes of stranding categories.

Results

The FWC reported 191 bottlenose dolphin strandings from 2011-2015. The vast majority of strandings were due to unknown reasons (142 out of 191), equaling 74 percent of the total number of stranding occurrences, as shown in Figure 1. The highest number of strandings with a known cause was due to morbillivirus, equaling 16 percent of the stranding occurrences (31 out of 191). Entanglement equaled three percent of the total number of stranding occurrences (six out of 191), while other diseases and human interaction fisheries equaled one percent (both were three occurrences out of 191). Asphyxiation and stillborn equaled one percent of the strandings (both were two occurrences out of 191). Starvation and blunt force trauma equaled only 0.5 percent, respectfully, of the total number of strandings (both were one occurrence out of 191), the least amount of all the categories.

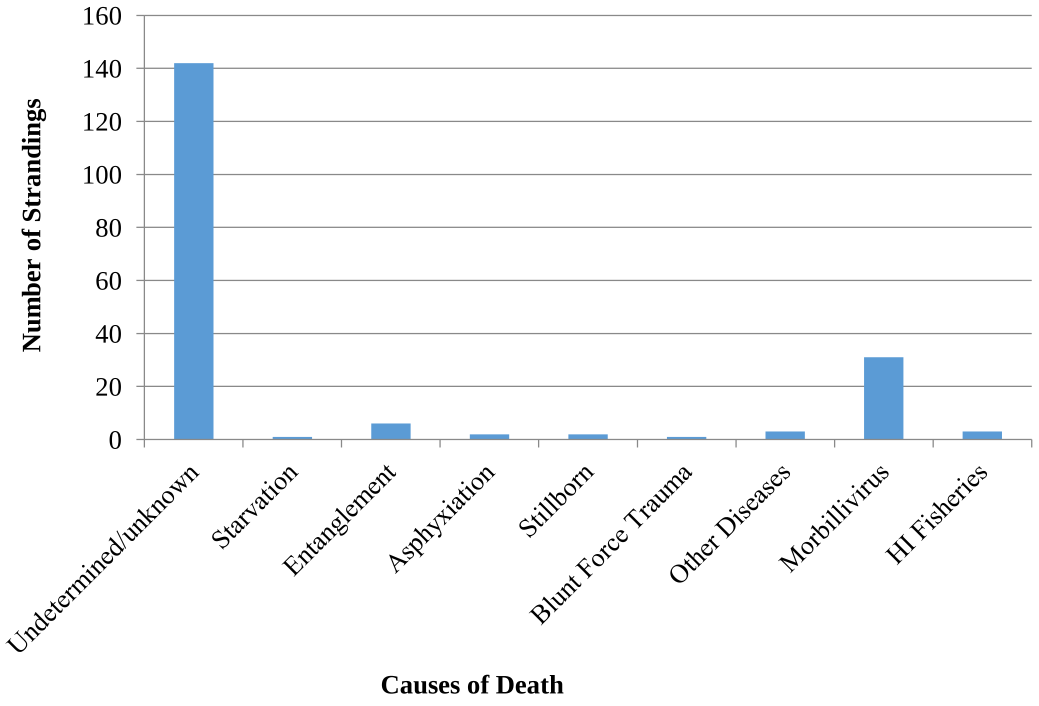

Figure 1: Graph of the various causes of death in bottlenose dolphin strandings from FWC off the coast of Jacksonville, FL during the years 2011-2015.

A Chi-Square goodness of fit test was used on the FWC data to determine whether the number of bottlenose dolphin strandings was significantly different among the causes of death categories. Using a 0.05 level of significance, the results indicate that the number of bottlenose dolphin strandings was significantly different from the causes of death categories (X^2=894.394; C.V. =15.507; d.f.=8; p-value=0.000).

McFee and Lipscomb (2009) reported 127 bottlenose dolphin strandings from 1993-2006 off the coast of North Carolina. The data are presented in Figure 2. The highest number of strandings recorded was due to noninfectious disease (human induced, fishery), equaling 18 percent of the total number of stranding occurrences (23 out of 127), as shown in Figure 2. Unknown causes of stranding accounted for 17 percent (21 out of 127), while infectious disease (bacterial) accounted for 15 percent (19 out of 127).

Noninfectious disease (emaciation) accounted for 13 percent of the total number of strandings, noninfectious disease (human interaction, boat trauma) accounted for nine percent (11 out of 127), and noninfectious disease (neonate) accounted for six percent (eight out of 127). Noninfectious disease (trauma, cause not evident) and noninfectious disease (stingray spine) accounted for 5.5 percent of the total number of strandings (both were seven occurrences out of 127), and infectious disease (verminous) accounted for five percent (six out of 127). Infectious disease (protozoal) and noninfectious disease (alimentary obstruction, natural object) accounted for two percent of the total number of strandings (both were two occurrences out of 127), while the cause of stranding categories of infectious disease (verminous and fungal), infectious disease (viral), infectious disease (agent unknown), noninfectious disease (drowning, cause not evident), and noninfectious disease (human interaction alimentary obstruction, man-made object) equaled only 0.8 percent of the total number of strandings (all were one occurrence out of 127), respectfully, the least amount of all of the categories.

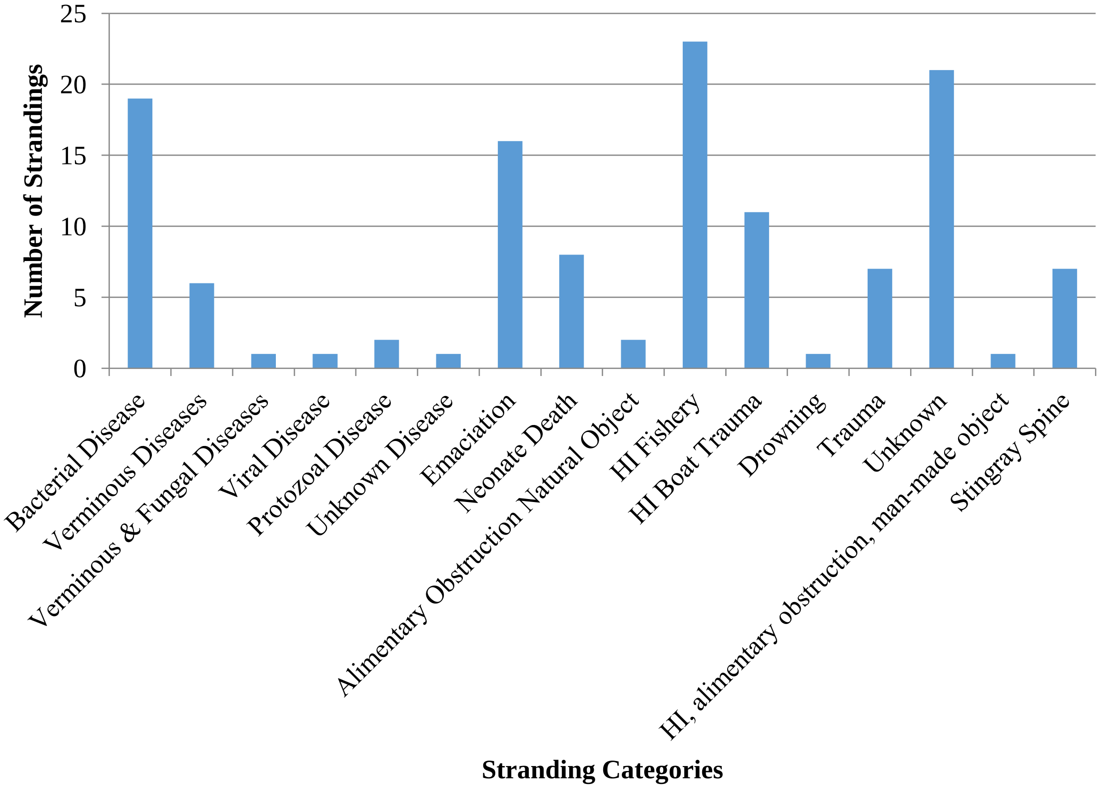

Figure 2: Graph of the various causes of strandings of bottlenose dolphins from McFee and Lipscomb (2009, 5-13) off the coast of North Carolina during the years 1993-2006. The category Verminous Diseases means diseases caused by vermin, and HI stands for human interaction.

AChi-Square goodness of fit test was used on the data from McFee and Lipscomb (2009, 5-13) to determine whether the number of bottlenose dolphin strandings was significantly different among the causes of stranding categories. Using a 0.05 level of significance, the results indicate that the number of bottlenose dolphin strandings was significantly different from the causes of stranding categories (X^2=114.88; C.V.=24.996; d.f.=15; p-value=0.000).

All cetacean strandings described in the researched literature, including both single and mass strandings, encompassed 30 species in 35 different locations. The most common locations for all cetacean strandings are the Canary Islands and Cape Cod. The Canary Islands have some of the most diverse array of cetacean species as it is located directly in the migratory path of many species (Arbelo et al. 2013, 87). The islands also have a subtropical climate conducive to the survival of many cetacean species and their prey, a lack of a continental shelf allowing coastal cetaceans to be able to forage closer to the coasts, abundant numbers of prey species such as cephalopods, and calm waters in the southwestern parts of the islands (Arbelo et al. 2013, 87). This has resulted in year-round populations of cetaceans being established in the Canary Islands (Arbelo et al. 2013, 87). Since the Canary Islands are a high traffic area for many species of cetaceans, strandings may occur more often or be reported more often.

Cape Cod is a hook-shaped land projection that extends into the Gulf of Maine (Bogomolni et al. 2010, 144). Within this area are the highly productive waters of Stellwagen Bank National Marine Sanctuary where large populations of prey items congregate and therefore large populations of cetaceans are found. Many of the species found along Stellwagen Bank are gregarious and frequently mass strand along the western shores of the northern part of Cape Cod. Historically, this area is one of the hot spots for cetacean strandings (Bogomolni et al. 2010, 144).

Using a 0.05 level of significance, a Chi-Square goodness of fit test was used to determine whether the number of cetacean strandings was significantly different among the stranding locations. The results indicate that the number of cetacean strandings was significantly different from the stranding locations (X^2=891.78; C.V.=52.192; d.f.=37; p-value=0.000).

The Canary Islands and Cape Cod account for 48 and 31 out of the 157 total stranding occurrences from the researched literature, respectfully, encompassing 18 and 12 different species, respectfully. Single strandings account for 70 out of the 157 total stranding occurrences. If stranding occurrences of a single individual were removed, there would be a total of 16 species of cetaceans that stranded in 27 different locations, as shown in Table 1.

The Canary Islands and Cape Cod are the most common locations of cetacean strandings (Table 1). Disease was the most common documented reason for stranding for all cetacean species and locations. The most common cetacean species that mass strands is the bottlenose dolphin, with nine stranding events. Striped dolphins were the second most common ceteacean species to mass strand, with eight stranding events. However, the striped dolphin had the most number of individuals strand in any location at any time. The most common reason for bottlenose dolphin strandings was disease and the most common location for this species to strand was the Canary Islands. As bottlenose dolphins were the species to strand most often, they will be the focus species of this capstone paper.

Table 1: Summary of information found on cetacean strandings by species, number of individuals, date, cause of stranding, location of stranding, and citation. This table is organized in alphabetical order by stranding locations and it includes only those considered as mass strandings.

Species	**Number in Stranding**	**Date of Stranding**	**Speculated Cause of Stranding**	**Stranding Location**	**Citation**
Bottlenose dolphin (*Tursiops truncatus*)	740	1987-1988	Disease	Atlantic coast of North America - New Jersey to central Florida	Lahvis et al. 1995; Rubio-Guerri et al. 2013
Blainville's beaked whale (*Mesoplodon densirostris*)	3	March 15-16, 2000	anthropogenic sound sources	Bahamas	Cox et al. 2006
Cuvier's beaked whale	9	March 15-16, 2000	anthropogenic sound sources	Bahamas	Cox et al. 2006
Common dolphin (*Delphinus* sp.)	6	May 2002	Cause not determined	Ballyvaughan Co. Clare on the west coast of Ireland	Jepson et al. 2013
Long-finned pilot whale (*Globicephala melas*)	5	March 2011	Unknown	Butlers Beach, Tasmania	Weijs et al. 2013
Common dolphin (*Delphinus* sp.)	10	1994	Unknown	California	Zagzebski et al. 2006
Long-beaked common dolphin (*Delphinus capensis*)	Unknown	2002	Domoic acid toxicity	California	Riva et al. 2009

Atlantic spotted dolphin (*Stenella frontalis*)	6	October 1999-September 2005	Acute death associated with any interaction with fishing activities	Canary Islands	Arberlo et al. 2013
Atlantic spotted dolphin (*Stenella frontalis*)	8	October 1999-September 2005	Pathology associated with poor nutritional status	Canary Islands	Arberlo et al. 2013
Atlantic spotted dolphin (*Stenella frontalis*)	8	October 1999-September 2005	Pathology assocaited with good nutritional status	Canary Islands	Arberlo et al. 2013
Beaked whales (including Cuvier's, Blainville's, and Gervais')	14	September 24, 2002	Military sonar	Canary Islands	Arberlo et al. 2013; Cox et al. 2006
Bottlenose dolphin (*Tursiops truncatus*)	4	October 1999-September 2005	Acute death associated with any interaction with fishing activities	Canary Islands	Arberlo et al. 2013
Bottlenose dolphin (*Tursiops truncatus*)	12-15	October 1999-September 2005	Mass stranding pathology	Canary Islands	Arberlo et al. 2013
Bottlenose dolphin (*Tursiops truncatus*)	27	1997-2011	Disease - PCB contamination	Canary Islands	García-Álvarez et al. 2014
Common bottlenose dolphin (*Tursiops truncatus*)	4	October 1999-September 2005	Pathology associated with poor nutritional status	Canary Islands	Arberlo et al. 2013
Common bottlenose dolphin (*Tursiops truncatus*)	3	October 1999-September 2005	Pathology assocaited with good nutritional status	Canary Islands	Arberlo et al. 2013

Common dolphin (*Delphinus* sp.)	3	October 1999-September 2005	Acute death associated with any interaction with fishing activities	Canary Islands	Arberlo et al. 2013
Common dolphin (*Delphinus* sp.)	5	October 1999-September 2005	Pathology associated with poor nutritional status	Canary Islands	Arberlo et al. 2013
Cuvier's beaked whale	4	July 2004	Military sonar	Canary Islands	Arberlo et al. 2013
Short-finned pilot whale (*Globicephala macrorhynchus*)	3	October 1999-September 2005	Pathology associated with poor nutritional status	Canary Islands	Arberlo et al. 2013
Sperm whale (*Physeter macrocephalus*)	6	October 1999-September 2005	Ship strike	Canary Islands	Arberlo et al. 2013
Spinner dolphin	5	October 1999-September 2005	Mass stranding pathology	Canary Islands	Arberlo et al. 2013
Striped dolphin (*Stenella coeruleoalba*)	3	October 1999-September 2005	Pathology associated with poor nutritional status	Canary Islands	Arberlo et al. 2013
Striped dolphin (*Stenella coeruleoalba*)	15	October 1999-September 2005	Pathology assocaited with good nutritional status	Canary Islands	Arberlo et al. 2013
Atlantic white-sided dolphin (*Langenorynchus acutus*)	14	2000-2006	Disease	Cape Cod	Bogomolni et al. 2010

Atlantic white-sided dolphin (*Langenorynchus acutus*)	46	2000-2006	Mass stranding - no significant finding	Cape Cod	Bogomolni et al. 2010
Atlantic white-sided dolphin (*Langenorynchus acutus*)	3	2000-2006	Abandoned calf	Cape Cod	Bogomolni et al. 2010
Harbor porpoise (*Phocoena phocoena*)	7	2000-2006	Disease	Cape Cod	Bogomolni et al. 2010
Harbor porpoise (*Phocoena phocoena*)	5	2000-2006	Predation	Cape Cod	Bogomolni et al. 2010
Harbor porpoise (*Phocoena phocoena*)	3	2000-2006	Abandoned calf	Cape Cod	Bogomolni et al. 2010
Long-finned pilot whale (*Globicephala melas*)	4	2000-2006	Disease	Cape Cod	Bogomolni et al. 2010
Long-finned pilot whale (*Globicephala melas*)	15	2000-2006	Mass stranding - no significant finding	Cape Cod	Bogomolni et al. 2010
Risso's dolphin (*Grampus griseus*)	4	2000-2006	Disease	Cape Cod	Bogomolni et al. 2010
Risso's dolphin (*Grampus griseus*)	3	2000-2006	Mass stranding - no significant finding	Cape Cod	Bogomolni et al. 2010
Short beaked common dolphin (*Delphinus delphis*)	20	2000-2006	Disease	Cape Cod	Bogomolni et al. 2010
Short beaked common dolphin (*Delphinus delphis*)	33	2000-2006	Mass stranding - no significant finding	Cape Cod	Bogomolni et al. 2010
Common dolphin (*Delphinus* sp.)	approx. 100	February 2002	Animals were trapped while preying upon fish	cove of Pleubian in the English Channel	Jepson et al. 2013; Viricel et al. 2008
Short beaked common dolphin (*Delphinus delphis*)	at least 24 - total number not known	June 9, 2008	Healthy when stranded - official cause not known	Falmouth Bay, UK	Jepson et al. 2013

Sperm whale (*Physeter macrocephalus*)	7	December 10-11, 2009	Prolonged starvation that lead to disorientation	Gargano Promontory in Italy	Mazzariol et al. 2011
Coastal bottlenose dolphin (*Tursiops* sp.) and short-beaked common dolphin (*Delphinus delphis*)	Unknown	1989-2003	Unknown	Great Australian Bight and Spencer Gulf	Bilgman et al. 2011
Cuvier's beaked whale	12	May 1996	Acoustic trials by vessels (could not be determined unequivocally)	Greece	Cox et al. 2006
Short-finned pilot whale (*Globicephala macrorhynchus*)	12	October 28, 1958	Navigational errors - bottom topography, geomagnetic anomalies	Kauai, Hawaii	Mazzuca et al. 1999
Short-finned pilot whale (*Globicephala macrorhynchus*)	28	May 10, 1959	Navigational errors - bottom topography, geomagnetic anomalies	Kauai, Hawaii	Mazzuca et al. 1999
Short-finned pilot whale (*Globicephala macrorhynchus*)	24	October 3, 1958	Navigational errors - bottom topography, geomagnetic anomalies	Lanai, Hawaii	Mazzuca et al. 1999
Striped dolphin (*Stenella coeruleoalba*)	9	February 2011-April 2012	Heart pathology	Ligurian Sea coast of Italy	Scaglione et al. 2013
Cuvier's beaked whale	3	May 10-14, 2000	Military sonar	Madeira	Cox et al. 2006
Pygmy killer whale (*Feresa attenuata*)	4	June 13, 1981	Navigational errors - bottom topography, geomagnetic anomalies	Maui, Hawaii	Mazzuca et al. 1999

Rough-toothed dolphin (*Steno bredanensis*)	18	June 27, 1976	Navigational errors - bottom topography, geomagnetic anomalies	Maui, Hawaii	Mazzuca et al. 1999
Rough-toothed dolphin (*Steno bredanensis*)	Unknown	June 28, 1976	Navigational errors - bottom topography, geomagnetic anomalies	Maui, Hawaii	Mazzuca et al. 1999
Rough-toothed dolphin (*Steno bredanensis*)	Unknown	June 30, 1976	Navigational errors - bottom topography, geomagnetic anomalies	Maui, Hawaii	Mazzuca et al. 1999
Striped dolphin (*Stenella coeruleoalba*)	thousands	1990-1991	Dolphin morbillivirus	Mediterranean Sea	Wierucka et al. 2014
Striped dolphin (*Stenella coeruleoalba*)	100	2007	Morbillivirus	Mediterranean Sea	Rubio-Guerri et al. 2013a; Rubio-Guerri et al. 2013b
Striped dolphin (*Stenella coeruleoalba*)	1000	1990-1992	Dolphin morbillivirus	Mediterranean Sea	Rubio-Guerri et al. 2013b
Striped dolphin (*Stenella coeruleoalba*)	1107+	July 1990-1992	Disease - Morbillivirus	Mediterranean Sea - Spanish, Italian, and Greek coasts	Aguilar and Raga 2013; García-Álvarez et al. 2014
Short-finned pilot whale (*Globicephala macrorhynchus*)	4	January 28, 1989	Navigational errors - bottom topography, geomagnetic anomalies	Molokai, Hawaii	Mazzuca et al. 1999
Common dolphin (*Delphinus* sp.)	15	February 2001	Cause not determined	Mullet Peninsula west coast of Ireland	Jepson et al. 2013
Bottlenose dolphin (*Tursiops truncatus*)	6	1997-2012	Parasites	Northern Patagonia coast	Romero et al. 2014

Common dolphin (*Delphinus* sp.)	133	2005-2012	Parasites	Northwest Iberian Peninsula along Galician coast	Reboredo-Fernández et al. 2014
Long-finned pilot whale (*Globicephala melas*)	55	December 2008	Unknown	Sandy Cape, Tasmania	Weijs et al. 2013
Long-finned pilot whale (*Globicephala melas*)	27	October 2006-April 2007	Dolphin morbillivirus	South coast of Spain	Wierucka et al. 2014
Long-finned pilot whale (*Globicephala melas*)	60	2007	Dolphin morbillivirus	Spanish Mediterranean coast	Rubio-Guerri et al. 2013b
Long-finned pilot whale (*Globicephala melas*)	53	November 2008	Unknown	Stanley, Tasmania	Weijs et al. 2013
Bottlenose dolphin (*Tursiops truncatus*)	3	March-April 2011	Dolphin morbillivirus	Valencian Mediterranean coast of Spain	Rubio-Guerri et al. 2013a; Rubio-Guerri et al. 2013b
Striped dolphin (*Stenella coeruleoalba*)	26	March-April 2011	Dolphin morbillivirus	Valencian Mediterranean coast of Spain	Rubio-Guerri et al. 2013a; Rubio-Guerri et al. 2013b
Unknown	8	March-April 2011	Dolphin morbillivirus	Valencian Mediterranean coast of Spain	Rubio-Guerri et al. 2013a; Rubio-Guerri et al. 2013b

Bottlenose Dolphin Life History

Bottlenose dolphins (*Tursiops truncatus*) are one of the most studied odontocete species in the world (Romero et al. 2014, 62; Worthy 1998, 47) and are one of the best known and easily recognized of the marine mammals (Vollmer and Rosel 2013, 1). There are two species of bottlenose dolphins commonly accepted: the common bottlenose dolphin (*Tursiops truncatus*) and the Indo-Pacific bottlenose dolphin (*Tursiops aduncus*) (3). Bottlenose dolphins are distributed throughout the globe in coastal and pelagic habitats excluding Arctic and Antarctic waters (Alonso et al. 2014, 627; García-Álvarez et al. 2014, 1; García-Álvarez et al. 2014, 23; Romero et al. 2014, 62; Vollmer and Rosel 2013, 1; Wilson et al. 1999, 288 Wirth et al. 2013, 659). They may live as far south as Tierra del Fuego, South Africa, Australia, and New Zealand in the Southern Hemisphere (Romero et al. 2014, 62). Bottlenose dolphins are found in shallow, warm tropical bays; pelagic waters; and cold water fjords (Vollmer and Rosel 2013, 2; Worthy 1998, 47). In the Northwest Atlantic and Pacific Oceans, two distinct ecotypes of bottlenose dolphins have been identified through genetics, distribution, diet, size, hematological data, parasite load, and skull morphology – coastal and pelagic (Bearzi et al. 2008, 98; Byrd et al. 2007, 72-73; Louis et al. 2014, 858; Natoli et al. 2006, 951; Vollmer and Rosel 2013, 3-4; Worthy 1998, 47)

Commonalities among Coastal and Pelagic Bottlenose Dolphins

Coastal and pelagic bottlenose dolphins are ecologically adapted to specific habitats, which may drive population structure (Bearzi et al. 2008, 96; Louis et al. 2014, 868; Natoli et al. 2006, 953). The range of the species is limited by ocean temperatures through prey distribution (Romero et al. 2014, 62; Vollmer and Rosel 2013, 7) and both males and females are philopatric, which means that they tend to remain in or return to the same location throughout their lives (Louis et al. 2014, 868). Bottlenose dolphins are apex predators and opportunistic feeders (Bearzi et al. 2008, 107; Vollmer and Rosel 2013, 7), which increases their exposure to toxic substances and diseases (Correa et al. 2013, 2441; Fire et al. 2008, 283). Because of this, these animals are considered sentinel species (Correa et al. 2013, 2441; Fire et al. 2008, 283; Twiner et al. 2011). The longevity of bottlenose dolphins is up to 57 years (Louis et al. 2014, 869) with females often living more than 50 years and males for more than 40 years (Vollmer and Rosel 2013, 6). Males have a higher mortality rate than females, which results in a biased sex ratio towards females as the animals age (6-7, 11) which could explain why female longevity is higher. Bottlenose dolphins are also sexually dimorphic (6) with males being larger in length, girth, and mass compared to females (6-7, 11). Male dolphins are approximately 2.6 m long and females are approximately 2.5 m long. Females reach maximum length by 10-12 years of age, whereas males continue to grow until they are about 20 years old (6-7, 11). Sexual maturity occurs between five and 14 years (Louis et al. 2014, 869) with male dolphins reaching sexual maturity at approximately eight to nine years of age, and females reaching sexual maturity at about six to seven years of age (Vollmer and Rosel 2013, 6-7, 11). Bottlenose dolphins have low reproductive rates (Wilson et al. 1999, 289) producing one calf every three to six years (Vollmer and Rosel 2013, 7; Wells et al. 2005, 113). However, the time of year birth occurs can be variable, as females may give birth year-round, but calving peaks occur in the spring and summer months (McFee and Hopkins-Murphy 2001, 263; Vollmer and Rosel 2013, 6-7, 11). Calves have a high mortality rate, with 50 percent of them not surviving past their first year of life (Vollmer and Rosel 2013, 6-7, 11). This may be attributed to contaminant loads found in the dolphins' tissues that affect health and reproductive success, but could also be attributed to predation and human interaction (6-7,11).

Coastal Bottlenose Dolphins

In the Northeast Atlantic, bottlenose dolphins reside primarily in coastal waters less than 40 m deep (Louis et al. 2014, 858). For example, Sarasota Bay, Florida and the surrounding area are home to a resident population of about 150 bottlenose dolphins that spans five generations and has been studied since 1970 (Correa et al. 2013, 2441; Fire et al. 2008, 285; Schwacke et al. 2002, 2753; Stewart et al. 2014, 93; Twiner et al. 2011; Vollmer and Rosel 2013, 6; Wells et al. 2005, 108). Based on skull morphology, the coastal ecotype is smaller in size (Vollmer and Rosel 2013, 4). In the southeastern United States, coastal populations are composed of resident stocks that reside year-round in local bays or are composed of coastal transient stocks that migrate seasonally (Worthy 1998, 47). Coastal populations feed mostly on estuarine species of fish, such as pinfish, striped mullet, pigfish, and spot (Fire et al. 2008, 284-285; Vollmer and Rosel 2013, 8) which comprise about 80 percent of their total diet (Fire et al. 2008, 284-285).

Pelagic Bottlenose Dolphins

Based on skull morphology, the pelagic ecotype is larger in size (Vollmer and Rosel 2013, 4). Pelagic populations of bottlenose dolphins feed mostly on demersal fish such as hake or blue whiting (Bearzi et al. 2003, 231; Louis et al. 2014, 868) as well as pelagic squid (Vollmer and Rosel 2013, 8).

Behavior and Sociology of Bottlenose Dolphins

Bottlenose dolphins are highly social animals (Wilson et al. 1999, 298). They live in fission-fusion societies in which animals associate in small groups that change in composition, often on a daily or hourly basis (Gero et al. 2005, 1567; López and Shirai 2008, 888; Vollmer and Rosel 2013, 6; Wilson et al. 1999, 298) which may allow the animals to adapt to environmental shifts and changes in prey availability (Bearzi et al. 2003, 231). These types of societies limit the effect of within-unit competition through the dispersal of pods during periods of high competition. Bottlenose dolphins also increase cooperative behavior through unit cohesion when the ecological costs of aggregating are low or the benefits of sociality are high (Bearzi et al. 2003, 231; López and Shirai 2008, 892).

A group of bottlenose dolphins is defined as consisting of one or more individuals that are usually involved in the same activity (Gero et al. 2005, 1567, 1571; López and Shirai 2008, 888-889). Contrasting patterns of associations have been seen among the different age classes and sexes of dolphins (Gero et al. 2005, 1567). Male bottlenose dolphins have been known to form stongly-bonded pairs that may last for ten years or more at a time (Gero et al. 2005, 1567, 1572; Vollmer and Rosel 2013, 6-7, 11). Female associations with each other and their dependent calves are found in the form of bands, or groups of females that tend to associate more with each other, sharing a similar home range (Gero et al. 2005, 1567, 1572; Vollmer and Rosel 2013, 6-7, 11). Females will associate with other females in the same reproductive state as they have the same feeding and predator avoidance requirements (Gero et al. 2005, 1571). Juveniles of both sexes tend to have more fluid associations with others because they are less constrained by social organization and reproduction than adults (1567, 1571-1572). Dolphins have signature whistles and individuals can recognize whistles from relatives (Vollmer and Rosel 2013, 6-7, 11). The whistles can also relay information on individual identity (6-7, 11). In the Northeast Atlantic, bottlenose dolphins form small resident or migratory groups consisting of tens to hundreds of individuals (Louis et al. 2014, 858). They also show varying degrees of residency and populations have shown a seasonal change in abundance which has been documented in areas such as Sanibel Island, Sarasota Bay, and Joseph Bay in Florida (Vollmer and Rosel 2013, 6).

Animals seen in the same foraging group may be considered associated (López and Shirai 2008, 889). Dolphin associations during feeding can be grouped into three categories: 1.) acquaintances, which never form preferred associations but are still associated in at least one feeding category (opportunistic or offshore); 2.) affiliates, which often form preferred associations across both feeding categories; and 3.) feeding associates, which form preferred associations within one feeding category, but not in both feeding categories (Gero et al. 2005, 1568, 1570-1571; López and Shirai 2008, 889, 893). López and Shirai (2008, 891-893) found that bottlenose dolphins choose male and female partners equally during feeding activities. The authors concluded that bottlenose dolphins show non-random social behavior during feeding activities and their social behavior differs depending on the current feeding activity (Gero et al. 2005, 1570-1571; López and Shirai 2008, 889, 892). This confirms that food acquisition drives the social organization of bottlenose dolphins (Gero et al. 2005, 1567, 1571; López and Shirai 2008, 892-893).

Discussion

Reasons for Mass Strandings

Few studies researched for this capstone have stated that there is any one reason why bottlenose dolphins strand themselves. Many of the strandings that have had a definitive cause have been due to a variety of factors. It is suggested in the literature that the majority of bottlenose dolphin strandings are ultimately caused by immunosuppressants that allow for multiple diseases to enter into the body. As the condition of the animal deteriorates, the likelihood of stranding significantly increases. This is further supported by the analyzed data from FWC and McFee and Lipscomb (2009, 5-13). It is not known whether diseases caused the majority of strandings of bottlenose dolphins in the analyzed FWC data off the coast of Jacksonville, FL, as an overwhelming majority of bottlenose dolphin strandings was due to an unknown cause. However, out of the known causes of strandings from the FWC and McFee and Lipscomb (2009, 5-13) data, diseases did comprise a significant portion of the stranding occurrences. With the FWC data, morbillivirus was the second most common cause of death for stranded bottlenose dolphins. With the data from McFee and Lipscomb (2009, 5-13), bacterial infections were the third most common cause of stranding for bottlenose dolphins, and infectious diseases in general comprised 28 percent of the total known stranding causes. These diseases by themselves may not have caused the strandings, but may have contributed to the occurrence of a stranding event. Immunosuppressants are now found worldwide even in the most remote of areas, so the likelihood of dolphins to be exposed to them is quite high (Hirai et al. 2011, 1688-1691). With these immunosuppressants already in the individual, it greatly increases the possibility that diseases can enter the body and further deteriorate the body, ultimately causing the stranding (Parsons and Jefferson 2000, 353; Baird 2001, 689; Bearzi et al. 2008, 107).

Finding a definitive cause of stranding can be difficult. Many of the animals that strand (either alive or dead) are well into decomposition by the time they are found. The body is not in a good enough condition to conduct a necropsy, and the cause of stranding remains unknown. This is especially true of the more pelagic bottlenose dolphins that would likely die at sea and float for days before finally landing on a beach as a dead stranding. There are even some dolphins that die at sea and never reach the shore and are therefore never counted. The idea of unknown stranding causes is further supported by the analyzed data from FWC and McFee and Lipscomb (2009, 5-13). With the data from FWC, undetermined/unknown was the leading cause of death in bottlenose dolphins, with 142 out of the 192 total cases. This means that the majority of bottlenose dolphins that stranded off the coast of Jacksonville, FL were likely too decomposed to make a definitive argument for the actual cause of death. With the data from McFee and Lipscomb (2009, 5-13), unknown was the second most cause of stranding of bottlenose dolphins. This means that many of the bottlenose dolphins that stranded off the coast of North Carolina were also likely to be too decomposed to get a definitive cause of stranding in these animals. Individuals that are too decomposed can only provide preliminary necropsy data and only minimal analyses can be conducted on the deceased. The rest of the capstone goes over the potential factors that can lead to a stranding of bottlenose dolphins.

Spatial Review of Mass Strandings

Many species observed in mass strandings are gregarious in nature and frequently mass strand on the western shores of Cape Cod as shown in Table 1(Bogomolni et al. 2010, 144). This area has one of the highest occurrences of mass strandings in North America. Between 2000 and 2006, 1,662 animals stranded along Cape Cod and southeastern Massachusetts, with 648 of those being live animals. During this period, disease was the leading cause of mortality for all species of stranded marine mammals, with the most prevalent diseases being bacterial/fungal pneumonia, septicemia/bacteremia caused by a skin infection, and parasitic infections (144, 146-147, 151). Along the United States Atlantic Coast, few strandings occur north of Cape Hatteras during the winter months (McLellan et al. 2002, 299). Stranding numbers are always highest between 34°N-36°N, and at 28°N (299-300).

Temporal Review of Mass Strandings

Bradshaw et al. (2005, 584) conducted an analysis of the periodicity of stranding events in the southeastern region of Australia, including one of the world’s stranding hotspots – the island of Tasmania. Their analysis indicated that there were clear cycles in the number of stranding events of approximately 12-14 year periods that are related to climatic variations. There may also be a seasonal periodicity of strandings (Peltier et al. 2014, 209). Mazzuca et al. (1999, 106) analyzed data from mass strandings of cetaceans in the Hawaiian Archipelago and concluded that stranding events tended to occur in the summer, with nearly 2/3 of them occurring during that time. The greatest frequency of strandings (34 percent) occurred in June, while 22 percent occurred in July and October and 11 percent occurred in May and January. Stranding events did not occur during the other seven months of the year. Mazzuca et al. (1999, 109) also concluded that 94 percent of the stranded individuals were adults and that 95 percent of the mass strandings were of live animals.

Other studies have also shown a seasonal periodicity in cetacean strandings. Arbelo et al. (2013, 93) conducted necropsies on stranded cetaceans in the Canary Islands between 1999 and 2005 and concluded that the highest number of strandings occurred in spring and summer. McFee and Hopkins-Murphy (2002, 260) conducted a five year study between 1992 and 1996 on stranded bottlenose dolphins in North Carolina and also saw a seasonal periodicity of strandings with the higest occurring in spring and the lowest number of strandings occurring in winter. In contrast, Byrd et al. (2007, 73) saw a spike of bottlenose dolphin strandings in the winter months off the coast of North Carolina during their study between November 1997 and April 2005. McFee et al. (2006, 197) conducted a seven year study between 1997 and 2003 on bottlenose dolphin strandings in North Carolina and found that the greatest number of strandings occurred in November and the least amount occurred in February and September. They also found that an equal number of strandings occurred in spring and fall, and the lowest amount occurred in winter, in contrast to the findings by Byrd et al. (2007, 73) conducted during the same time period. This difference in findings could be attributed to any number of factors such as human error, a different population of dolphins, or being in a different location off the coast. Bottlenose dolphin strandings occurring between 1987 and 1988 along the United States Atlantic Coast from New Jersey to Florida showed an increase from June to August with a peak in August, a decrease through November, and then an increase again through January (McLellan et al. 2002, 299, 301). Bottlenose dolphins found in Texas also seem to follow a seasonal pattern in strandings, with 60 percent of them occurring between February and April (Worthy 1998, 48).

General Overview of All Causes of Mass Strandings

It is still not known why cetaceans mass strand (Mazzuca et al. 1999, 105; Mazzariol et al. 2011; Arbelo et al. 2013, 97; Jepson et al. 2013) or whether they strand deliberately or accidentally (Mazzuca et al. 1999, 105). The frequency of mass mortalities of marine mammals, including mass strandings of live stranded individuals that ultimately died and dead stranded individuals has increased substantially in the latter half of the 20th century (Burek et al. 2008, S128; Harwood 2001, 635). The likely cause for this increase is the greater movement of humans and their domestic animals into coastal areas, which has resulted in the introduction of new pathogens into populations, sometimes causing the populations to become sick and strand (Zagzebski et al. 2006, 334; Deem et al. 2001, 1225; Harwood 2001, 635; Young 1994, 415).

Many different theories for mass strandings exist and the cause of stranding events is on a case-by-case basis (Arbelo et al. 2013, 97). The hypothesis that mass strandings of apparently healthy cetaceans is due to the tendency of the pod to follow a leader has been supported (Mazzuca et al. 1999, 105; Bogomolni et al. 2010, 151; Mazzariol et al. 2011; Jepson et al. 2013; Weijs et al. 2013, 118). These pods have strong social cohesion that has been observed mostly in pilot whales and occasionally in bottlenose dolphins (Arbelo et al. 2013, 97; Bogomolni et al. 2010, 151).

Other theories for mass strandings can include disease, neonatal death, pollutants, entanglement in fishing or aquaculture gear, boat strikes, and intentional killing (Simeone et al. 2015, 2; Reboredo-Fernández et al. 2014, 136; Weijs et al. 2013, 118; Bilgmann et al. 2011; Mazzariol et al. 2011; McFee et al. 2006, 196; Galimberti et al. 2001, 86; Harwood et al. 2001, 630; McFee and Hopkins-Murphy 2001, 264). Live strandings also occur as a result of the pursuit of prey, predator avoidance, geomagnetic forces along the ocean floor, damage to the middle ear due to parasitic infection, harmful algal blooms, and disorientation due to underwater sound (Reboredo-Fernández et al. 2014, 136; Weijs et al. 2013, 118; Mazzariol et al. 2011; Bogomolni et al. 2010, 151; Cox et al. 2006, 184; Baird 2001, 688). Animals that live strand may also become trapped on a receding tide, be affected by navigational errors associated with topography (Jepson et al. 2013; Mazzariol et al. 2011), be subject to unusual environmental conditions such as extreme storms and earthquakes (Bradshaw et al. 2005, 584; Jepson et al. 2013), strand as a response to over-population, changes in the phases of the moon, and following ancient migratory routes that no longer exist (Mazzariol et al. 2011; Mazzuca et al. 1999, 105). Other possible causes of mass mortalities of marine mammals include climate and oceanographic variation (Mazzariol et al. 2011; Bogomolni et al. 2010, 151; Bradshaw et al. 2005, 584; Galimberti et al. 2001, 86), navigational errors due to variations in magnetic configurations, or bathymetric and ocean current features, and anthropogenic noise and sonar, as well as sensory stimulation, distraction, and regression to instinctive behaviors (Mazzariol et al. 2011; Bradshaw et al. 2005, 584). Because of these possible causes of strandings, mass mortalities of marine mammals seem likely to become more frequent in the future (Harwood 2001, 635).

Every species of cetacean has been observed in a single stranding (Bogomolni et al. 2010, 143). These types of strandings are usually explained as natural mortality due to disease, injury, weather, and prey availability (Mazzuca et al. 1999, 105; Young 1994, 414) – or anthropogenic causes of mortality due to toxic pollutants or other forms of human activity (Mazzuca et al. 1999, 105). It has been suggested that mass strandings occur under different circumstances than single strandings and seem to be unique to odontocetes (Pyenson et al. 2014, 4; Arbelo et al. 2013, 97; Weijs et al. 2013, 118). However, there was one occurrence of a mass stranding of mysticete cetaceans or baleen whales between the end of 1987 and the beginning of 1988 near Cape Cod that involved 15 humpback whales, four minke whales, and two fin whales (Pyenson et al. 2014, 4; Mazzuca et al. 1999, 106; Aguilar and Raga 1993, 526). The cause of the stranding was attributed to toxins found in the mackerel in their stomachs with effects similar to that of paralytic shellfish poisoning (Pyenson et al. 2014, 4; Mazzuca et al. 1999, 106).

Diseases

Marine diseases have increasingly been reported over the past few decades (Daszak et al. 2001, 106). Bogomolni et al. (2010, 152) reported disease was the leading cause of death among marine mammals. Diseases such as bacterial infections, some of which are caused by bacteria found in sewage that is transferred to marine mammals through ingestion of contaminated prey or through wounds, are a major cause of stranding events (Parsons and Jefferson 2000, 353). However, viruses and parasitic infections occur more frequently than bacterial infections (Parsons and Jefferson 2000, 353).

Immunotoxins

Marine mammals can become more susceptible to diseases after being exposed to immunotoxins, or compounds toxic to the immune system, in the marine environment (Parsons and Jefferson 2000, 353; Baird 2001, 689; Bearzi et al. 2008, 107). When mass mortality events occur, immunotoxin contamination, as well as the depletion in available prey, are often mentioned as potentially contributing factors (Bearzi et al. 2003, 237; Wilcox and Elderd 2003, 860; Young 1994, 413). These animals that are immunocompromised are usually emaciated when they strand, possibly supporting the idea that their prey is scarce or that the disease has caused them to lose their appetite (Arbelo et al. 2013, 95; Bearzi et al. 2003, 237). Those prey species that are not depleted may also be contaminated with carcinogens as well as inhabit contaminated seabeds (Parsons and Jefferson 2000, 352), potentially causing immunotxin contamination and subsequent diseases and strandings.

Unusual Mortality Events (UMEs)

So-called unusual mortality events (UMEs) are strandings that are unexpected, invlolve a significant die-off of any marine mammal population, and require an immediate response from the scientific community. They are different from mass strandings in that they can occur over a period of months or even years and can include groups of mass stranding events that have a causative link as well as include different species of marine animals, whereas a mass stranding is one event over a period of hours or days and typically includes just one species of the odontocete whales. UMEs are events in which the animals that strand ultimately die as a result of the stranding, whereas mass strandings can have animals survive the stranding event. But both events can have the same causes and a mass stranding event can even be a part of an ongoing UME.

It is important to understand what causes UMEs because they serve as indicators of overall ocean health. UMEs are a relatively common occurrence in the Gulf of Mexico and may have tens to hundreds of bottlenose dolphins die during the course of the event (Vollmer and Rosel 2013, 19). Bottlenose dolphin deaths associated with mass die-offs of other marine species have been documented since at least 1946. There have been 12 documented large-scale events in the Gulf of Mexico since 1990, with nearly two thousand marine mammals, primarily bottlenose dolphins, having stranded during these events. Since February 2010 to at least 2013 or later, concurrent with the Deepwater Horizon oil spill, there has been an ongoing UME in the northern Gulf of Mexico affecting Louisiana, Mississippi, Alabama, and the Florida panhandle, during which over one thousand cetaceans, mostly bottlenose dolphins, have stranded. According to the Marine Mammal Commission Annual Report in 2009, between 1991 and 2007, 34 percent of UMEs affecting marine mammals in the United States occurred in the Gulf of Mexico (Vollmer and Rosel 2013, 19-20).

Diseases

Density Dependent vs. Frequency Dependent Diseases

The transmission of diseases among marine mammals, including bottlenose dolphins, may depend on the density of the population or the frequency of occurrence of the disease in the population (Shimizu et al. 2014, 630; Burek et al. 2008, S127; Altizer et al. 2003, 522, 524; Wilcox and Elderd 2003, 860; Young 1994, 414). Density-dependent diseases are diseases in which infection occurs through random contacts between infected and susceptible individuals (Burek et al. 2008, S127; Altizer et al. 2003, 518, 520), much like how people transfer viruses to one another. The likelihood that an animal will be infected depends on the density of the infected population, so the larger the population, the more likely that a density-dependent disease will run through the population

(Simeone et al. 2015, 11; Burek et al. 2008, S127; Lafferty et al. 2004, 38; Altizer et al. 2003, 520, 522; Wilcox and Elderd 2003, 860).

Bottlenose dolphins are also highly social animals that live in fission-fusion societies, or small groups that change in composition on a daily or hourly basis. This maximizes the number of exposed individuals through direct contact as infected individuals come into contact with healthy individuals through the change in pod composition. It also increases the likelihood that a density-dependent disease will run through populations at a faster rate compared to other species of cetaceans, potentially doing more damage to the population. Diseases in this category include morbilliviruses, which cause die-offs of several thousand individuals at a time (Burek et al. 2008, S127). Frequency-dependent diseases depend on the number of diseased animals in the population. With these types of diseases, the more animals in a population that have the disease, the greater the frequency healthy individuals will contract the disease. These types of diseases are less well documented but they are found in terrestrial mammals and are transmitted through sexual contact, a vector, or contact within a social group. Many marine mammal diseases that affect bottlenose dolphins are likely to be both density- and frequency-dependent due to the social nature of these animals (Burek et al. 2008, S127; Altizer et al. 2003, 524).

Coastal Water Contamination and Frequency of Disease Deaths

Contamination of coastal waters due to run-off and wastewater discharges can carry microbiological pollutants such as bacteria, viruses, and protozoa that can cause disease in bottlenose dolphins (Stewart et al. 2014, 91; Lafferty et al. 2004, 38, 47). These pathogens can be transported in the water or the air to novel areas, posing a serious health risk to the dolphins in the area (Stewart et al. 2014, 91; Lafferty et al. 2004, 47). Infectious disease has been identified as the most significant cause of mortality of marine vertebrates, including bottlenose dolphins, having been associated with 31 percent of known deaths based off of necropsy and histopathology data. This number is higher than the number of deaths caused by trauma, infant mortality, or bycatch (Stewart et al. 2014, 92). There is also evidence that the frequency of diseases is increasing, causing large-scale mortality events in bottlenose dolphin populations (Lafferty et al. 2004, 32, 47; Baird 2001, 689).

Morbillivirus

Mass mortality events caused by lymphotropic morbillivirus infections have affected many cetacean populations throughout the world (Bilgmann et al. 2011; Mazzariol et al. 2011; Daszak et al. 2001, 106) and may have been implicated in the mortality of more than half of the population of United States Atlantic bottlenose dolphins (Bearzi et al. 2008, 107; McFeee and Hopkins-Murphy 2002, 258; McLellan et al. 2002, 297-298; Taubenberger et al. 1996, 213). Threats from viral outbreaks may affect bottlenose dolphin populations differently, and may be a particular threat to smaller populations, which raises conservation concerns, especially for some areas of the Gulf of Mexico (Vollmer and Rosel 2013, 19-20). Some of the UMEs occurring in the Gulf of Mexico between 1991 and 2007 have been attributed to morbillivirus (19-20). Another morbillivirus outbreak in 1990-1991, caused thousands of striped dolphins to strand dead on the beaches of the Mediterranean Sea (Rubi-Guerri et al. 2013, 1; Wierucka et al. 2013, 2; Aguilar and Raga 1993, 526). Between 1987 and 1988, there were a total of 742 calculated cases of morbillivirus in bottlenose dolphins along the United States Atlantic coast (Simeone et al. 2015, 10; McFee et al. 2006, 195; McLellan et al. 2002, 297; Taubenberger et al. 1996, 213; Aguilar and Raga 1993, 526). The stranding event started off the coast of Viriginia, moved to New Jersey in the summer, and then to central Florida in the winter (McLellan et al. 2002, 297). Outbreaks with fewer calculated cases were seen in Gulf of Mexico bottlenose dolphins between 1993 and 1994 (Simeone et al. 2015, 10; Worthy 1998, 48; Taubenberger et al. 1996, 213). Morbillivirus was also implicated in the deaths of 201 bottlenose dolphins during a UME in 1990 in the Gulf of Mexico (Worthy 1998, 52). A nearly identical virus was found in stranded pilot whales (Wierucka et al. 2014, 2) suggesting interspecies transmission of the virus is possible (Wierucka et al. 2014, 2; Forcada et al. 1999, 257; Taubenberger et al. 1996, 216). Morbillivirus is transmitted through mucus membranes and pilot whales may be vectors of the virus for other cetacean species (Wierucka et al. 2014, 2; Taubenberger et al. 1996, 216). Morbillivirus is an enveloped negative-strand RNA virus (Rubio-Guerri et al. 2013, 109; Zagzebski et al. 2006, 342). It is a significant cause of death among cetaceans compared to other pathogens found and has been causing mass die-offs of marine mammals since the late 1980s (Groch et al. 2014, 511-512; Stephens et al. 2014, 666; Rubio-Guerri et al. 2013, 1; Shimizu et al. 2013, 2). In fact, the first morbillivirus outbreak affecting bottlenose dolphins along the mid-Atlantic occurred during the late 1980s (Sierra et al. 2014, 269; Rubio-Guerri et al. 2013, 109; McFee and Hopkins-Murphy 2002, 258; McLellan et al. 2002, 297; Worthy 1998, 53; Taubenberger et al. 1996, 213; Aguilar and Raga 1993, 526) effectively killing 50 percent of the population (Rubio-Guerri et al. 2013; McLellan et al. 2002, 297-298), and it is thought that morbillivirus was the cause of more than 500 bottlenose dolphins stranding in the mid-Atlantic in 2013 (Sierra et al. 2014, 269). Morbillivirus may also lay dormant in cetaceans between outbreaks which can lead to endemic infections and spreading among naïve populations, causing death at epidemic proportions (Stephens et al. 2014, 668). This scenario was seen for common dolphins in the eastern North Pacific, for Mediterranean striped dolphins, and for pilot whales (668). Morbillivirus is a member of the family Paramyxoviridae (Groch et al. 2014, 511; Rubio-Guerri et al. 2013, 1), which includes other diseases such as measles virus (MV) in humans, rinderpest virus (RPV) in cows, peste de petits ruminants virus in sheep and goats, and canine distemper virus in dogs (Groch et al. 2014, 511; Stephens et al. 2014, 667; Taubenberger et al. 1996, 213).

Morbillivirus is split into two new types: phocine distemper virus which targets mostly seals and cetacean morbillivirus (CMV) which targets mostly dolphin species (Groch et al. 2014, 511; Shimizu et al. 2014, 2). Cetacean morbillivirus is further split into three other types of viruses: porpoise morbillivirus, dolphin morbillivirus (DMV) which was first identified in striped dolphins from the Mediterranean Sea, and pilot whale morbillivirus (Groch et al. 2014, 511; Sierra et al. 2014, 269; Stephens et al. 2014, 666; Rubio-Guerri et al. 2013, 1; Rubio-Guerri et al. 2013, 110). CMV more closely resembles ruminant morbilliviruses and human measles than canine and phocine distemper viruses (Stephens et al. 2014, 666). All morbilliviruses target the lymphoid tissues and are immunosuppressive in nature (Shimizu et al. 2014, 3; Stephens et al. 2014, 666, 668; Aguilar and Raga 1993, 526). They may also cause emaciation, pneumonia, and meningoencephalitis (Groch et al. 2014, 512; Aguilar and Raga 1993, 526), and may be concurrently present with parasites such as *Toxoplasma gondii* and *Brucella* spp. (Rubio-Guerri et al. 2013, 4), as well as cause diseases affecting the upper respiratory tract and central nervous system (CNS), ultimately leading to strandings and subsequent deaths (Rubio-Guerri et al. 2013, 4; Rubio-Guerri et al. 2013, 109; Aguilar and Raga 1993, 526). Morbilliviruses are known to infect marine mammals worldwide but only one fatal case in a bottlenose dolphin has been confirmed in the Southern Hemisphere (Groch et al. 2014, 511). Subclinical morbillivirus infection with immune suppression has also been confirmed in bottlenose dolphins off the coast of Florida, including in Sarasota Bay (Groch et al. 2014, 512; Vollmer and Rosel 2013, 19-20).

Pathogen Transmission and Disease Outbreaks

Other diseases found in bottlenose dolphins include peritonitis, septicemia, hepatitis, aspergillosis, and bacterial enteritis (Stewart et al. 2014, 92). Pathogen transmission in marine environments is usually associated with the consumption of contaminated shellfish or finfish, or through contact with contaminated seawater (100) from terrestrial inputs which may change habitat quality or prey availability (Hughes et al. 2013, 982). These terrestrial contaminants may increase pathogen prevalence, causing disease outbreaks in bottlenose dolphins and subsequent mass strandings (982). Also, the level of pollution, climate change, anthropogenic activity, and the availability of prey may influence the prevalence and severity of diseases via imunnosuppression, which may be a factor in stranding events (Shimizu et al. 2014, 630; Wierucka et al. 2014, 2; Lafferty et al. 2004, 38; Deem et al. 2001, 1225). Disease outbreaks occur when a carrier of the disease comes into contact with a susceptible host (Burek et al. 2008, S128). The effects of disease outbreaks on bottlenose dolphin populations are difficult to evaluate due to the protection status of these animals and the environment in which they live, so few studies have evaluated the effect of disease on the survival rate of a dolphin population (Wierucka et al. 2014, 2). As global climate change continues to affect the Earth, temperature increases are predicted to increase the susceptibility of bottlenose dolphins to disease and contaminants through increased physiological stress or movement of animals to new areas where they would be exposed to new pathogens or where they could introduce new pathogens into resident populations, increasing the likelihood of mass stranding events occurring (Seymour et al. 2014, 154, 162; Vollmer and Rosel 2013, 20; Burek et al. 2008, S126-S127; Lafferty et al. 2004, 32, 35, 39; Altizer et al. 2003, 535; Deem et al. 2001, 1227).

Emerging Diseases

Over the past few years emerging diseases, defined as diseases that have recently increased in geographic range, moved into new host populations, or have recently been discovered or are caused by newly evolved pathogens (Daszak et al. 2001, 103), have been reported in many cetaceans, including bottlenose dolphins, with increasing frequency (Van Bressem et al. 2014, 181; Hughes et al. 2013, 982). These diseases are causing massive die-offs of bottlenose dolphins (Van Bressem et al. 2014, 181; Daszak et al. 2001, 111) affecting reproduction and causing skin lesions (Van Bressem et al. 2014, 181). Bottlenose dolphins and other odontocetes have been increasingly observed with cutaneous nodular and granulomatous lesions over the last twenty years (181). In smaller inshore populations, these lesions may cover the majority of the body and have been associated with the death of individuals (182). Fungi species such as *Lacazia loboi*, *Fusarium* spp., *Paracoccidioides brasiliensis*, and *Trichophyton* spp., as well as the bacteria *Streptococcus iniae* have been implicated in some of these nodular disorders (182, 187). *L. loboi* has caused immune suppression in coastal populations of bottlenose dolphins in Florida (182). Genital, cutaneous, and oral papillomas, as well as fibropapillomas have also been frequently found in these dolphins (187). Fibropapillomas are caused by the virus *Papillomaviridae*, and are usually found on the skin of many terrestrial mammals (187).

There is evidence of an emerging disease in the marine environment called a polyomavirus (Anthony et al. 2013, 1). To date, it has only been observed in a short-beaked common dolphin (1), but poses a threat to other dolphin species such as bottlenose dolphins. Polyomaviruses (PyVs) are small, non-enveloped viruses that infect a wide range of avian and mammalian hosts with varying severity. Mammalian PyVs usually result in mild or subclinical infections unless the host has been immunosuppressed, in which case strandings may occur as a result of the virus. PyVs can cause lesions in the upper airways of the trachea and bronchi, which may cause the dolphin to become lethargic and stop eating, effectively causing anorexia, and if the animal becimes weak enough, strandings occur (Anthony et al. 2013, 1). PyVs may also cause respiratory disease in dolphins (3).

Another disease that had rarely been observed in bottlenose dolphins was heart disease (Scaglione et al. 2013, 31). Most of the previous cases reported were infections, parasites, and malformations (31). Scaglione et al. (2013, 31-35) had studied heart pathologies of stranded dolphins and found aneurysms in the pulmonary trunk and right sinus of Valsalva in three of the cases. They also discovered Lambl's excrescences, which are filament-like fronds on the valves of the aorta, in four of the stranded dolphins. A correlation between Lambl's excrescences and neurological effects has been hypothesized (Aziz and Baciewicz 2007, 366-368). They may also cause brain embolisms if they break apart, which would manifest themselves as strokes and cerebrovascular lesions. According to Scaglione et al. (2013, 35), these heart pathologies had not been previously described in marine mammals and should be taken into account as possible causes of bottlenose dolphin strandings.

Vibrio

There is evidence of high levels of waterborne pathogens and bacteria in stranded bottlenose dolphins (Wallace et al. 2013, 201). Marine pathogens of the genus *Vibrio* are facultative anaerobes that can be found worldwide in these animals (Hughes et al. 2013, 983; Burek et al. 2008, S128). Pathogenic strains may show up when the environment has been altered and nonpathogenic strains may be passed on genetically. Ingesting pathogenic *Vibrio* may cause gastroenteritis, dehydration, septicemia, and in some cases death (Hughes et al. 2013, 983). The occurrence of *Vibrio* in bottlenose dolphins has increased and it may be transferred via gestation and lactation. This group of bacteria is very diverse and versatile, allowing it to thrive in nearly any marine environment. Infectious species of *Vibrio* have been found in bottlenose dolphins, including those found in the southeast United States (990). They have the ability to cause disease or death in debilitated dolphins, leading to stranding events, and many species are associated with different diseases (Buck et al. 2006, 542). However, the specific involvement of these *Vibrio* species in diseases and stranding events are not well known (542).

Antimicrobial Resistance and Brucella

Zoonotic pathogens, defined as diseases that can be transmitted from animals to people (Daszak et al. 2001, 104; Deem et al. 2001, 1229), have shown traits of antimicrobial resistance (AMR) and occur naturally in the environment through natural selection (Wallace et al. 2013, 201-202). Factors such as anthropogenic pollutants and human waste contamination can affect AMR and pollutants may actually be a major cause of AMR in marine microbes. This has caused a significant increase in AMR over time in the marine environment (202). AMR genes are a concern as they can increase pathogen resistance, create new pathogens, and alter microbial populations, which could in turn cause more stranding events to occur (201-202).

Brucella strains that affect marine mammals were first isolated in 1994 in both the Atlantic and Pacific (Sidor et al. 2013, 72). *Brucella ceti* affects cetaceans, while *Brucella pinnipedialis* affects pinnipeds. Evidence suggests that *Brucella* causes an enzootic or endemic disease in bottlenose dolphins called brucellosis, the effects of which include abortion, placentitus, inflammation of the testicles, visceral and blubber abscesses, musculoskeletal lesions, and meningoencephalitis (72). These conditions can disable the dolphin (Isidoro-Ayza et al. 2014), making it harder to swim and potentially causing a stranding event. Bottlenose dolphins that stranded off the coast of Cornwall in southwest England between June 2004 and December 2007 were found to have brucellosis (Davison et al. 2011, 4-5). A few of these animals were found to have very high levels of organic pollutants in their system, which have been known to increase the susceptibility of bottlenose dolphins to other infectious diseases, such as *Brucella ceti* (5). As *Brucella* is considered a newly-discovered disease in marine mammals, very little is known about the specific effects it has on stranding events other than the relationship it has with organic pollutants.

Skin Diseases

Bottlenose dolphins are subject to skin diseases. Lobomycosis is a chronic fungal disease caused by *Lacazia loboi*, a fungal pathogen that has been documented in stranded dolphins (de Moura et al. 2014, 16). This disease is relatively new in dolphins but has been hypothesized to be associated with exposure to persistent contaminants combined with exposure to ballast water from ships that may dump *L. loboi* into the ocean based off of findings from previous stranding data (16). It may also cause immunosuppression in bottlenose dolphins, potentially leading to stranding events. Another skin disease that has been found in bottlenose dolphins and other dolphin species is tattoo skin disease (TSD) (16). This disease causes stippled skin lesions on the body and has only been reported in adults. It is caused by poxviruses and does not seem to increase mortality among dolphins, although exposure to naïve populations can cause strandings and may kill off neonates and calves that have no immunity (de Moura et al. 2014, 16-17).

Gastroenteritis

Little is known about the gastrointestinal microbes found in marine mammals or what microbes cause disease (Diaz et al. 2013). Gastroenteritis is found in bottlenose dolphins and can be diagnosed based on abnormal fecal or gastric content, changes in gut motility and appetite, or overgrowth of *Candida* spp. or *Clostridium perfringens* in feces. The effects of gastrorenteritis include anorexia, lethargy, and oral lesions, all of which could be a factor in strandings. Dolphins are particularly susceptible to gastric ulcers because they lack glands in the forestomach to protect against digestive fluids and hydrochloric acid. *Helicobacter* infections such as *Helicobacter cetorum* may increase the effects of gastric ulcers in dolphins. Other pathogens that can affect gastrointestinal health and may be a factor in bottlenose dolphin strandings include astroviruses, *Campylobacter* spp., *Clostridium* spp., *Edwardsiella tarda*, *Giardia* and *Cryptosporidium* species, and *Salmonella* spp. (Diaz et al. 2013). These pathogens by themselves may not cause stranding events, but they can compromise the immune system and allow other diseases to enter into the body, ultimately causing the stranding.

Parasites

Parasites are commonly found in cetaceans and are the cause of death in juveniles more than adults (Bogomolni et al. 2010, 150). Parasite transmission mostly occurs through ingestion of infected prey (Baird 2001, 689). In many cases, more than one parasite or disease is found in stranded individuals (Romero et al. 2014, 62; Arbelo et al. 2013, 91), and pulmonary nematodes are a commonly observed parasite in stranded bottlenose dolphins (Arbelo et al. 2013, 91) as well as trematodes and cestodes (Baird 2001, 689; Dailey and Walker 1978, 593). Immunodepression associated with viral infections allows ciliate protozoa to thrive in bottlenose dolphins (Arbelo et al. 2013, 95). Also, high concentrations of persistent organic pollutants have been suggested to be associated with parasite burdens in these animals (Reboredo-Fernández et al. 2014, 135; Pierce et al. 2008, 413). Warmer ocean temperatures due to climate change cause some parasites to grow faster, have decreased generation times, or higher reproductive rates, suggesting the severity of disease increases with temperature (Lafferty et al. 2004, 40).

Nasitrema

Parasites such as trematodes of the genus *Nasitrema* sp. can be a significant cause of stranding in various odontocete species, including bottlenose dolphins, affecting the central nervous system and causing brain lesions (Dailey and Walker 1978, 595), neuropathy in the eighth cranial nerve, encephalitis, and cerebral necrosis (Arbelo et al. 2013, 95). The parasite can also affect the auditory nerves and has been observed in bottlenose dolphin mass stranding events (97). It is also one of several species of parasites including liver flukes (Brachycladiidae), lungworms (Pseudaliidae), and tissue nematodes (Crassicaudidae) that cause mortality events (Balbuena and Simpkin 2014, 84).

Crassicauda

Many species of the genus *Crassicauda* can become several meters long in host tissues, are endemic to cetaceans (Balbuena and Simpkin 2014, 84), and have been found in bottlenose dolphins. They are found in the urogenital system, mammary glands, abdominal muscle, and cranial sinuses and can cause extensive damage to the body. The parasite can also infect calves via transfer from the mother during lactation. Prevalence of the parasite increases during the first years of life, causing mortality mostly in juvenile bottlenose dolphins (87). *Crassicauda* sp. can cause cranial bone lesions that are a result of bone erosion by enzymes secreted by the parasite (84). These lesions are specific to *Crassicauda* and are thought to be irreversible, which allows scientists to be able to determine whether the animal had previous infections. These bone lesions are uncommon in older individuals, suggesting that *Crassicauda* sp. are a major cause of mortality (84) in younger bottlenose dolphins. The cranial infections caused by *Crassicauda* sp. can lead to an intense inflammatory reaction that may affect echolocation, potentially causing the animals to strand, or cause bacterial and viral infections (Balbuena and Simpkin 2014, 84) which would further compromise the immune system and could potentially cause the animals to strand.

Campula

Trematodes of the genus *Campula* are one of the most frequent parasitic infections observed in the digestive system of bottlenose dolphins and other cetaceans (Jaber et al. 2013, 79). They primarily inhabit the bile and pancreatic ducts, causing extreme irritation of the ducts, fibrosis (Jaber et al. 2013, 79-80; Dailey and Walker 1978, 595), biliary hyperplasia, and inflammation caused by lymphocytes, plasma cells, and eosinophils, which causes hard whitish nodules to form on the liver (Jaber et al. 2013, 79-80). These effects on hepatic function also cause a metabolic disorder of the central nervous system called hepatic encephalopathy (79), which causes a loss of brain function, leading to confusion and disorientation. The disoriented dolphins will not know where they are going, and can end up stranding themselves. During stranding, blood flow is compressed, leading to liver congestion and hypoxia, which causes the equivalent of human congestive heart failure in bottlenose dolphins (82).

Toxoplasma gondii

Another parasitic disease of concern is toxoplasmosis, which is caused by the opportunistic protozoan parasite *Toxoplasma gondii* (de Moura et al. 2014, 15; Mazzariol et al. 2011). It is a potentially fatal disease transmitted by cats (Lafferty et al. 2004, 44; Daszak et al. 2001, 107) that has been found in marine mammals, including bottlenose dolphins, (de Moura et al. 2014, 15) as well as all other mammal species, birds, and up to 1/3 of the world's human population (Simon et al. 2013, 150). Wild and domestic felids are the only definitive hosts and contaminate the environment with oocysts secreted from their feces (150). The parasite gets into the marine environment via surface runoff water (150). It is thought that a single oocyst may cause infection by *T. gondii* (158). Bottlenose dolphins do not directly ingest oocysts in the surrounding water as they get most of their water intake from their food. Oocysts likely get into dolphins through an intermediate host, such as various bivalves found in the surrounding environment. Mussels and oysters are able to remove *T. gondii* oocysts from contaminated water, which remain viable and infective within their tissues. These bivalves act as the source of infection for bottlenose dolphins directly through the food chain (Reboredo-Fernández et al. 2014, 136; Romero et al. 2014, 67; Simon et al. 2013, 158). The bivalves and even microcrustaceans that take up the *T. gondii* are consumed by small fish and cephalopods which are then consumed by bottlenose dolphins (Reboredo-Fernández et al. 2014, 136). In most cases, *T. gondii* infection is asymptomatic (Simon et al. 2013, 150), but infection does occur when contaminated food and water has been ingested, and it may also be transferred from mother to calf during pregnancy (de Moura et al. 2014, 15). It is likely that any bottlenose dolphins having toxoplasmosis will also have another disease such as morbillivirus as well as high levels of organochlorine pollutants, as clinical cases have been associated with immune suppression caused by persistent pollutants and infection by morbilliviruses (15). It is hypothesized that the amount of diseases in the body coupled with the immunosuppressants will compromise the immune system and may make the animals more susceptible to stranding events.

Giardia and Cryptosporidium

Giardia has also been found in stranded dolphins (de Moura et al. 2014, 15; Reboredo-Fernández et al. 2014, 136), as well as *Cryptosporidium* (Reboredo-Fernández et al. 2014, 132-136). *Giardia* is a parasite that infests the small intestine, causing diarrhea, abdominal cramps, bloating, malabsorption, and weight loss (de Moura et al. 2014, 15). However, both *Giardia* and *Cryptosporidium* have been found in such small amounts in dolphins that it is unlikely that these parasites alone cause strandings (Reboredo-Fernández et al. 2014, 136). These parasites compromise the immune system (de Moura et al. 2014, 15), and it is hypothesized that the compromised immune system can allow other parasites and diseases into the body, ultimately causing the stranding.

Parasites in Bottlenose Dolphins

Parasites found in bottlenose dolphins include the digeneans *Braunina cordiformis*, *Synthesium tursionis*, *Brachycladium atlanticum*, and *Pholeter gastrophilus*; the acanthocephalans *Bolbosoma* sp. and *Corynosoma cetaceum*; the nematode *Anisakis simplex*; and the cestodes *Tetrabothrius forsteri*, *Diphyllobothrium* sp. and *Strobilocephalus triangularis* (Romero et al. 2014, 62). The effects these parasites have on the immune system in dolphins can lead to stranding events. Romero et al. 2014 (62-63) described the presence of parasites in bottlenose dolphins in the southwestern Atlantic Ocean off the coast of Patagonia and found that all bottlenose dolphins necropsied had helminths. They also found seven total species of parasites including the nematodes *Anisakis simplex* s.1. and *Pseudoterranova decipiens*; the acanthocephalans *Corynosoma cetaceum* and *C. australe*; and the digeneans *Braunina cordiformis*, *Pholeter gastrophilus* and *Synthesium tursionis*. The species found most often (over 80 percent of the time) included the nematode *Anisakis simplex* found in the stomach and the acanthocephalan *Corynosoma cetaceum* found in the stomach and intestines.

Corynosoma cetaceum had the highest mean abundance. Three helminth species were found in the intestines: *Corynosoma australe*, *Synthesium tursionis*, and *C. cetaceum*. All helminth species found in the dolphins were in the adult stage (Romero et al. 2014, 62-63).

Five of the seven helminth species found in bottlenose dolphins during this study are also known to infect other odontocete cetaceans, including the helminths *Corynosoma cetaceum*, *Braunina cordiformis*, *Anisakis simplex*, *Pholeter gastrophilis*, and *Synthesium tursionis*. *A. simplex*, *P. gastrophilis*, and *S. tursionis* are also found in bottlenose dolphins in the Northern Hemisphere (Romero et al. 2014, 62-63). The helminths *C. australe* and *Psuedoterranova decipiens* are usually found in pinnipeds, and their description in bottlenose dolphins in this study represents a new host record. The family Brauninidae is specificically found in delphinid species and the species found in this study, *Braunina cordiformis*, attaches itself to the stomach lining and intestines and has been previously found in other bottlenose dolphins. Another species, *Sythesium tursionis*, also shows high specificity to bottlenose dolphins, especially in the Mediterranean Sea, and is also found in dolphins in the southwestern Atlantic (Romero et al. 2014, 62-67).

Pollutants

Persistent Organic Pollutants (POPs)

Cetacean species are good indicators of organic pollutants in the environment as they are considered sentinel species (Simeone et al. 2015, 2; Alonso et al. 2014, 620; de Moura et al. 2014, 2-3, 5; Law 2014, 9; Reboredo-Fernández et al. 2014, 136; Zhu et al. 2014, 66; Cagnazzi et al. 2013, 493; Dorneles et al. 2013, 310; Hughes et al. 2013, 982; Lemos et al. 2013, 167; Panebianco et al. 2013, 511; Weijs et al. 2013, 117; Fire et al. 2008, 283; Worthy 1998, 47). Persistent organic pollutants (POPs) are lipophilic anthropogenic chemical compounds that remain in the environment for significant amounts of time (García-Álvarez et al. 2014, 1; Gui et al. 2014, 107; Ellisor et al. 2013, 581; Ochiai et al. 2013, 804; Dorneles et al. 2010, 60; Pierce et al. 2008, 402; Lafferty et al. 2004, 40)[1]. Because these compounds do not biodegrade, they bioaccumulate in organisms (García-Álvarez et al. 2014, 1; Gui et al. 2014, 107; Ko et al. 2014, 131-132; Zhu et al. 2014, 66; Dorneles et al. 2013, 310; Law et al. 2013, 81; Panebianco et al. 2013, 511; Weijs et al. 2013, 117; Bogomolni et al. 2010, 144; Dorneles et al. 2010, 60; Bearzi et al. 2008, 107; Pierce et al. 2008, 402; Lafferty et al. 2004, 40; Bearzi et al. 2003, 238; Schwacke et al. 2002, 2752; Baird 2001, 692). This bioaccumulation may pose a serious threat to those organisms higher on the food chain, such as cetaceans (Law 2014, 7; Ko et al. 2014, 127; Lemos et al. 2013, 167; Weijs et al. 2013, 117-118; Pierce et al. 2008, 402; Evans et al. 2004, 486; Lafferty et al. 2004, 40). Cetaceans, especially coastal cetaceans such as bottlenose dolphins which have more exposure to POPs (Ochiai et al. 2013, 804), are particularly susceptible to the bioaccumulation of POPs in their blubber due to their long life spans and their large fat deposits (Alonso et al. 2014, 620; Bachman et al. 2014, 115-116; Law 2014, 9; Méndez-Fernandez et al. 2014, 197; Gui et al. 2014, 107; Zhu et al. 2014, 66; Cagnazzi et al. 2013, 490; Dorneles et al. 2013, 315; Weijs et al. 2013, 117; Pierce et al. 2008, 402; Evans et al. 2004, 486; Schwacke et al. 2002, 2752). Compared to most terrestrial mammals, marine mammals seem to have a lower capacity to metabolize POPs (Méndez-Fernandez et al. 2014, 197; Evans et al. 2003, 486; Schwacke et al. 2002, 2759). This capacity is even lower in odontocetes compared to pinnipeds (Méndez-Fernandez et al. 2014, 197; Nomiyama et al. 2014, 20; Schwacke et al. 2002, 2759), and in males compared to females (Ko et al. 2014, 130; Dorneles et al. 2013, 314; Promislow 1991, 1875), which makes toothed whales such as bottlenose dolphins particularly vulnerable to the negative effects of POPs with regards to the health and reproductive system (Ellisor et al. 2013, 581). To illustrate, between the summer of 1987 and the spring of 1988, over 740 bottlenose dolphins stranded along the Atlantic coast from New Jersey to Florida (Lahvis et al. 1995, 67; Schwacke et al. 2002, 2753). This event may have depleted the population by as much as 53 percent. It was concluded that the dolphins had numerous diseases due to a suppressed immune system associated with increased levels of polychlorinated biphenyls (PCBs) and DDTs in the

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[1] POPs are the primary pollutants of concern in the marine environment cited on the OSPAR (so named because of the original Oslo (OS) and Paris (PAR) Conventions, but today is a 16 member cooperative to protect the marine environment of the Northeast Atlantic) list of Chemicals for Priority Action (Méndez-Fernandez et al. 2014, 197).

blood (Lahvis et al. 1995, 67-71; Burek et al. 2008, S130; Schwacke et al. 2002, 2753). DDTs are one of the more prevalent POP compounds found in free-ranging bottlenose dolphins, as concluded by García-Álvarez et al. (2014, 28). García-Álvarez et al. (2014, 28) also concluded that all pesticides found in their study, which assessed POP concentrations in free-ranging bottlenose dolphins, exceeded the threshold level of toxicity. One of notable concern was the high levels of endrin found in the animals. This pesticide was found in free-ranging bottlenose dolphins, but not in stranded animals, suggesting that endrin may be easily broken down by exposure to high temperatures or light, which dolphins are more exposed to during stranding. Endrin is known to be highly toxic to aquatic organisms and may cause long-term adverse effects on aquatic ecosystems (28). Other events involving the stranding of bottlenose dolphins have occurred, including an event between January and May 1990 during which time approximately 350 bottlenose dolphins stranded from Texas to Florida (Schwacke et al. 2002, 2753). Another event occurred in 1992 in a smaller portion of the same area. In both cases, high concentrations of POPs were found in the tissues of the stranded animals and are thought to be associated with the strandings (2753).

POPs enter the tissues almost exclusively through ingestion of prey items, as opposed to ingestion of seawater or through the air, and can vary greatly depending on the prey type and local environmental pollution (Gui et al. 2014, 107; Méndez-Fernandez et al. 2014, 199; Ochiai et al. 2013, 806; Weijs et al. 2013, 117; Pierce et al. 2008, 402, 407; Evans et al. 496). Lipid content in cetaceans drives the distribution of POPs in the blubber (Ko et al. 2014, 128; Ellisor et al. 2013, 587). During times of food scarcity when lipids are metabolized, POPs found in the blubber get moved into the blood compartment, which end up circulated in the blood stream (Ellisor et al. 2013, 585; Mazzariol et al. 2011; Evans et al. 2004, 497). It is hypothesized that this may at least in part explain the emaciation often seen in dolphins when they strand. The POPs get into the blood stream where they can be circulated and have negative effects on the health of the individual, potentially causing that animal to strand (Ellisor et al. 2013, 585).

Chemicals classified as POPs include PCBs, polybrominated diphenyl ethers (PBDEs), and organochlorine pesticides (OCPs) (Ellisor et al. 2013, 581; Bachman et al. 2014, 115; García-Álvarez et al. 2014, 1; Pierce et al. 2008, 402). These organic pollutants are found in everyday items such as electrical transformers, pesticides, and flame retardants (Bachman et al. 2014, 115; Dorneles et al. 2013, 310; Ochiai et al. 2013, 803), and have been produced since the 1940s (Méndez-Fernandez et al. 2014, 197). Despite the ban on PCB production since the 1970s in many developed countries (Nomiyama et al. 2014, 15; Ochiai et al. 2013, 803), and an international ban on their use in 2004 under the Stockholm Convention on Persistent Organic Pollutants, PCBs are still found in the environment (Nomiyama et al. 2014, 15). The toxic effects of PCBs are also seen in the hydroxylated metabolites of PCBs (OH-PCBs) (Ochiai et al. 2013, 803). OH-PCB congeners have chemical structures similar to thyroid hormones and circulate in the blood, potentially disrupting thyroid function (803-804). They have also been known to have neurological effects during development (Ochiai et al. 2013, 803-804).

Fifty thousand metric tons of PBDEs are produced annually worldwide and it is estimated that 40 percent of this amount is used in North America (Alonso et al. 2014, 620). They were used as flame retardants and in many consumer products to help stop the spread of fire (Ko et al. 2014, 127; Zhu et al. 2014, 65). Their structural similarity to other POPs with known toxic effects suggests that PBDEs may pose health risks as well (de Moura et al. 2014, 10), and in fact, PBDEs have had effects on the steroid and thyroid hormones and on the immune and reproductive systems in mammals (Alonso et al. 2014, 620, 632; Ko et al. 2014, 127, 132; Dorneles et al. 2010, 60; Pierce et al. 2008, 402). Because of these negative effects, the Penta-BDE and Octa-BDE mixtures have been banned in the European Union and were included in the Stockholm Convention on Persistent Organic Pollutants (Ko et al. 2014, 127; Zhu et al. 2014, 65). The historical trend of other POPs has shown a decrease in concentrations found in the environment due to the banning of several of them, whereas the concentrations of PBDEs have shown an exponential increase (Alonso et al. 2014, 629). PBDE levels can vary depending on the exposure to the contaminant, species, gender, and age (Ko et al. 2014, 128). PBDE levels seem to be higher in odontocete cetaceans compared to mysticete cetaceans since they have a diet found in a higher trophic level (Alonso et al. 2014, 620), and bottlenose dolphins found in Charleston, South Carolina have some of the highest PBDE levels measured in cetaceans (627). Juveniles tend to have the highest concentrations compared to other age classes, and coastal cetaceans have higher concentrations of pollutants compared to pelagic cetaceans (Weijs et al. 2013, 121). There is evidence that concentrations of PBDEs and other POPs decrease in cetaceans with age (123). One possible explanation for this is that as juveniles, cetaceans cannot metabolize pollutant concentrations as well as older adults (123). The concentrations of PBDEs in cetaceans from Japan, China, the United States, and Canada coastal waters have significantly increased over the last 30 years (Alonso et al. 2014, 630).

POPs are transported to the ocean through agricultural runoff, atmospheric transport, combustion, and ocean circulation (Bachman et al 2014, 115; Cagnazzi et al. 2013, 490; Weijs et al. 2013, 117). They are known endocrine disruptors, and have been known to cause immunosuppression, cancer, skin lesions, secondary infections and diseases, die-offs, and reduced reproductive success (de Moura et al. 2014, 2; García-Álvarez et al. 2014, 2; García-Álvarez et al. 2014, 23; Gui et al. 2014, 107; Law 2014, 7; Ko et al. 2014, 127; Méndez-Fernandez et al. 2014, 201; Nomiyama et al. 2014, 15; Van Bressem et al. 2014, 187; Cagnazzi et al. 2013, 493; Dorneles et al. 2013, 310, 314, 316; Weijs et al. 2013, 117-118; Bogomolni et al. 2010, 144; Bearzi et al. 2008, 107; Burek et al. 2008, S130; Pierce et al. 2008, 402; Evans et al. 2004, 486-487; Lafferty et al. 2004, 40; Bearzi et al. 2003, 238; Schwacke et al. 2002, 2752; Baird 2001, 689, 693; Daszak et al. 2001, 111; Deem et al. 2001, 1227; Harwood 2001, 634-635; Aguilar and Raga 1993, 5270). PCBs have been known to negatively affect the thyroid hormone in animals, which is critical for the development of the central nervous system and brain function (Nomiyama et al. 2014, 15). PCBs were also reported to have been involved in the development of a morbillivirus epizootic in the Mediterranean Sea between 1990 and 1992, affecting striped dolphins (García-Álvarez et al. 2014, 2; Aguilar and Raga 1993, 527). Many articles have been published since this event about contaminant levels in cetaceans and their facilitation in infectious diseases (García-Álvarez et al. 2014, 2; Weijs et al. 2013, 118; Pierce et al. 2008, 402, 413). Some of these articles were written about bottlenose dolphins as several adverse health effects of pollutant concentrations have been seen in this species as well. Correlated concentrations have been found of PCBs and DDTs in the blood of inshore bottlenose dolphins with a decline in their immune system function. There is also evidence of a toxic potential of the chemical load found in dolphins (García-Álvarez et al. 2014, 2; García-Álvarez et al. 2014, 23; Cagnazzi et al.

2013, 492; Schwacke et al. 2013, G; Bearzi et al. 2003, 238) which is often exceeded in these animals (García-Álvarez et al. 2014, 23; Cagnazzi et al. 2013, 492-493; Pierce et al. 2008, 408). This can lead to adverse health effects such as anemia, thyroid disorder, or immunosuppression (García-Álvarez et al. 2014, 27). According to Méndez-Fernandez et al. (2014, 199-200), bottlenose dolphins had the highest mean PCB concentrations among the five species studied. They also found juvenile bottlenose dolphins had high concentrations of PCBs as well, which are in accordance with their coastal habitat, their proximity to highly populated areas with high pollutant concentrations, and their main prey species being fish. The concentration of contaminants in the tissues, however, can vary depending on prey consumption, body size and composition, nutritive condition, age, sex, health status, duration of lactation, and transfer of the contaminant load from mother to offspring during pregnancy and lactation (197).

Perfluorooctane sulfonate (PFOS) is an eight-carbon chain of perfluoroalkyl acid (PFAA) and is considered an emerging POP contaminant of concern due to its global distribution and unknown potential effects on wildlife (Wirth et al. 2013, 658). PFOS's were phased out in United States markets in 2001 after increasing concentrations were found in people and wildlife. It was used in many products including stain repellents and firefighting foams. Like other POPs, PFOS bioaccumulates, but unlike other POPs, it is both lipophobic and hydrophobic and binds to plasma proteins found in the blood and liver. Because it bioaccumulates and biomagnifies, PFOS is of concern to organisms in higher trophic levels such as cetaceans (658). It has been found in bottlenose dolphins and the Charleston, South Carolina population has some of the highest serum levels. PFOS has been shown to cause liver damage, neurotoxicity, be developmentally toxic, and alter endocrine and immune functions (658-659). It has also shown to be found in higher levels in cetaceans compared to other pollutants (de Moura et al. 2014, 10). It is important to determine the health status of these animals as their health is an indication of pollutant concentrations in the marine environment (de Moura et al. 2014, 2-3; Dorneles et al. 2013, 310). These animals are also protected species, and so their health status is important for determining population status and future protections on the species.

Organochlorines

More than 30 years have passed since scientists have recognized the possible health and reproductive effects of organochlorines (OCs) on marine mammals, but little actual research has been done on the matter (Wells et al. 2005, 107). High concentrations of OCs have been found in marine mammals after mass stranding events, and there is a need to understand the role OCs play in mass strandings (107). Contaminant concentrations found in free-ranging populations of bottlenose dolphins in the southeastern United States are currently being measured by Dr. Randall Wells and his team with the Sarasota Dolphin Research Program in Sarasota, FL as part of an ongoing study of the resident dolphins in the area. Accumulation of OC concentrations in males continue throughout their lives (Schwacke et al. 2013, C; Evans et al. 2004, 494), whereas in females, concentrations decline with reproductive activity, as they transfer their contaminant loads to their young via the placenta and lactation (Alonso et al. 2014, 630; Bachman et al. 2014, 120; de Moura et al. 2014, 9-10; Gui et al. 2014, 110-111; Ko et al. 2014, 130; Lebeuf et al. 2014, 378, 382, 384; Méndez-Fernandez et al. 2014, 199; Dorneles et al. 2013, 314; Jepson et al. 2013; Dorneles et al. 2010, 66; Pierce et al. 2008, 411-412; Wells et al. 2005, 107; Evans et al. 2004, 494; Schwacke et al. 2002, 2754). Comparison of the blubber concentrations of OCs to the presence of ovarian scars show that female dolphins transfer 80 percent of their body burden of OCs to calves via lactation (García-Álvarez et al. 2014, 7; Vollmer and Rosel 2013, 7; Weijs et al. 2013, 122; Wells et al. 2005, 107; Evans et al. 2004, 495). This transfer of contaminants occurs predominantly in the first seven weeks of life (Wells et al. 2005, 107), with the first-born offspring receiving the majority of the mother's contaminant load (Lebeuf et al. 2014, 384; Vollmer and Rosel 2013, 7; Wells et al. 2005, 107-108; Evans et al. 2004, 495; Schwacke et al. 2002, 2754). In García-Álvarez et al. (2014, 5), age classifications of bottlenose dolphins stranded off the coast of the Canary Islands between 1997 and 2011 were determined. Out of 27 stranded dolphins, nine were adults, ten were subadults, six were juveniles, one was a calf, and one was a newborn (García-Álvarez et al. 2014, 5).

Organochlorine concentrations are being studied in the Sarasota, Florida population of bottlenose dolphins. Using tagging, tracking, and photographic identification, it has been possible to identify individual home ranges and monitor female reproductive histories including reproductive success (Wells et al. 2005, 108). Scientists in Sarasota are also utilizing capture and release techniques to examine the health and reproductive status of dolphins. Blubber and other tissue samples have been collected during these capture and releases of dolphins for analysis of OC residues. These techniques provide a method to gain accurate measures of OC concentrations and compare them to life history parameters and reproductive success, which could lead to a better understanding of the effects OCs have on bottlenose dolphins (Wells et al. 2005, 108).

Male and female bottlenose dolphins in Sarasota had similar concentrations of OCs of about 15-50 ppm until they reached sexual maturity (Wells et al. 2005, 108). Male concentrations then continued to increase with age, with the highest concentration found at 860 ppm in a dolphin 43 years old. Female concentrations of OCs tend to decline to relatively low levels after reaching sexual maturity at 5-10 years of age, and remain low throughout their lives because they transfer their contaminant load to their calves. Concentrations of OCs in the blubber of females are related to reproductive condition, so the highest concentrations were found in females that had not yet given birth. Concentrations of OCs decline after the first calf is born and remain low thereafter. According to Wells et al. (2005,108) in Sarasota, FL, some increase in the concentration of OCs is seen in adult female dolphins after giving birth to their first calf, which supports the idea that first-born calves have a higher exposure to OCs while nursing than subsequent offspring. Concentrations of OCs in calves tend to be between 10-50 ppm, relatively the same concentrations found in the adults. OC concentrations would have more adverse affects on the calves compared to the adults because of their small size. The higher exposure first-born calves have to OC concentrations leads to a higher mortality rate as 50 percent of first-born calves in Sarasota Bay observed during 1982-2002 died during their first year of life. This is compared to less than 30 percent of calves born to multiparous mothers dying during their first year of life. Also, an increase in the risk of reproductive failure for a first-time mom could increase the age at first birth, which could impact the future growth and stability of the population (Wells et al. 2005, 107-117; Schwacke et al. 2002, 2761). Another concern is the increase in OC concentrations seen in females between the births of their calves, which suggests that these compounds remain in the environment and may have an impact on populations for future generations (107-117). Once the calves reach maturity, an increase in OC concentrations can lead to a decline in immune system function (Wells et al. 2005 107-117), which could allow diseases to wreak havoc on the immune system and ultimately cause strandings.

Heavy Metals and Trace Elements

Heavy metals, defined as nonessential trace elements, bioaccumulate in organisms and are of particular concern in marine mammals due to their higher trophic level status (Seixas et al. 2014, 32; Panebianco et al. 2013, 511). Heavy metals have been found in the epithelial and muscle tissues of dolphins (Lemos et al. 2013, 169; Panebianco et al. 2013, 511). Biological parameters such as length, weight, age, sexual maturity, and body condition (Lemos et al. 2013, 169; Panebianco et al. 2013, 511), as well as environmental variables and feeding habits (Lemos et al. 2013, 169) can influence the effects these heavy metals have on individuals. Some trace elements are necessary for the body to function and their deficiency can actually cause problems (137). These are essential trace elements. However, they are considered toxic like nonessential elements when in excess and can disrupt the metabolic process (167). Their toxicity depends on the time of exposure and the amount of the element present in the body, and they can cause serious adverse effects on marine mammals such as immunosuppression, which can lead to infections caused by pathogens, abnormal tissue growths, skin and organ lesions, reproductive failure, and mass mortality events (Lemos et al. 2013, 167). Essential trace elements include copper, manganese, selenium, and zinc and nonessential trace elements include cadmium and mercury (Lemos et al. 2013, 169).

Coastal cetaceans such as bottlenose dolphins have a reduced territorial range compared to oceanic species and are important indicators of local environmental contamination (169). Bottlenose dolphins usually accumulate trace elements differently than oceanic species, mostly due to their feeding habits (169). Panebianco et al. 2013 (512, 514) studied the presence of heavy metals in dolphins off the coast of Buenos Aires and found that the concentrations of zinc and nickel were higher than any of the other heavy metals found, including cadmium, lead, copper, and chromium. Also, sexually mature males had a lower body condition than sexually immature males, sexually immature females, and sexually mature females (514). Mercury, specifically methylmercury which is more toxic, is of particular interest as it is the only metal that bioaccumulates and biomagnifies over the entire marine food web, potentially exposing top-level predators to high concentrations in their diet (Seixas et al. 2014, 274, 276; Seixas et al. 2014, 32, 38; Correa et al. 2013, 2441). Biomagnification of metylmercury is greater in pelagic and bentho-pelagic food chains compared to benthic food chains (Seixas et al. 2014, 274; Seixas et al. 2014, 38). Methylmercury has toxic effects and can affect the productivity, reproduction, and survival of coastal cetaceans such as bottlenose dolphins (Seixas et al. 2014, 274; Seixas et al. 2014, 33; Correa et al. 2013, 2441). It is absorbed and transported through the blood-brain barrier and placenta and can have neurotoxic effects (Correa et al. 2013, 2441; Lemos et al. 2013, 172). These neurotoxic effects can cause bottlenose dolphins to become disoriented and strand. Nearly all mercury found in the muscle tissues of dolphins and other marine mammals is methylated, but the type of mercury found in their internal organs such as the liver is inorganic, suggesting that it is possible for the mercury to become demethylated (Seixas et al. 2014, 33). Selenium, a trace element essential for metabolic activity, may help to demethylate mercury, reducing the toxicity (Seixas et al. 2014, 33; Correa et al. 2013, 2441). Selenium has been found in large quantities in marine fish, which can be advantageous to dolphins and other marine mammals that eat those fish (Seixas et al. 2014, 33). However, the ratio of mercury compared to selenium can be much higher, which could pose serious health risks on prey fish and subsequently on marine mammals, causing them to possibly strand. Selenium also does not biomagnify over the entire food web (35). It is only passed from primary producers to foraging fish, so dolphins and other marine mammals do not see the direct positive effects selenium has on mercury concentrations (35).

Marine Debris

The majority of what is known about marine debris, including its effect on marine mammals such as bottlenose dolphins, comes from stranded individuals (Baulch and Perry 2014, 210). After collecting and analyzing worldwide data from marine mammal stranding networks, Baulch and Perry (2014, 212) determined that debris ingestion was documented in at least 462 individual cetaceans from 48 different species – nine mysticete cetaceans and 39 odontocete species, representing 56 percent of all cetacean species. The number of cetaceans that ingested marine debris has steadily increased since the 1960's, which shows that ingestion of marine debris is a problem in cetaceans, including bottlenose dolphins (219). It is estimated that 6.4 million tons of trash enter the oceans every year (210). Plastic constitutes approximately 60 to 80 percent of that and it does not fully biodegrade for hundreds to thousands of years (210), allowing it to persist in the marine environment (Baulch and Perry 2014, 210).

The biggest issues regarding marine debris are ingestion and entanglement (Baulch and Perry 2014, 210). Ingestion of debris may cause the digestive tract to be blocked, leading to starvation. Entanglement can lead to drowning, suffocation, or even strangulation. Entanglement and ingestion of marine debris can also negatively affect feeding and digestion, which could cause malnutrition, disease, reduced fecundity, reduced growth, and decreased longevity. Particularly, plastics pose a huge threat to marine animals as the chemical additives in plastics are persistent and bioaccumulate and biomagnify in the ocean. Cetaceans most commonly ingested plastics (46 percent), with fishing gear (12 percent), miscellaneous (11 percent), and unidentified (30 percent) constituting the rest of the debris found (219). The size of ingested items ranged from less than 5 mm to large plastic sheeting or netting and had pathological effects anywhere from no effects to complete blockage of the digestive tract, causing malnutrition, starvation, and eventual stranding or death. 6.3 percent of bottlenose dolphins in the United Kingdom were found to have ingested marine debris, compared to none of the striped dolphins in Croatia. It is thought that interspecies variability of debris ingestion comes from geographical differences in debris abundance and feeding habits (Baulch and Perry 2014, 212).

Ingestion of marine debris by cetaceans was first reported in the 1890's, with the first record of ingestion of plastic debris occurring in the 1970's, twenty years after mass-production of synthetic materials began (Baulch and Perry 2014, 218). Scientists believe that ingestion of marine debris may actually occur at the time of stranding rather than be the immediate cause of stranding, or that ingestion of marine debris may actually increase the likelihood that an animal may strand and thus be over-represented in stranded individuals (219). It is thought that in many species and regions of the world debris ingestion rarely causes mortality. There are exceptions to this in the Canary Islands and Croatia where evidence suggests that debris ingestion is a significant cause of mortality in cetaceans. Even if strandings caused by ingestion are over-represented, such high rates should be of concern as they could be a significant conservation threat in these cetacean populations. However, there is a lack of data on sub-lethal pathology in cetaceans from marine debris, which may include injury and disease, decreased growth rates, lethargy, and decreased reproductive rate. Sub-lethal effects could have more of an impact at the population level than immediate mortality caused by debris. For example, microplastic ingestion can occur via several different routes, and toxins from microplastics bioaccumulate in the food chain, potentially having the same effects as other toxins on cetaceans, including strandings. Quantities of microplastics have also increased 100-fold over the last 40 years, and they are virtually impossible to remove from the ocean, creating a serious potential threat to cetaceans and other marine animals (219).

Harmful Algal Blooms

Harmful algal blooms (HABs) have increased in distribution, intensity, and frequency over the past few decades, concerning scientists on the effects these toxins might have on various animal species, including bottlenose dolphins (Simeone et al. 2015, 7; Burek et al. 2008, S130; Fire et al. 2008, 283). HABs are a population explosion of single-celled, photosynthetic marine algae that produce potent toxins such as saxitoxin, domoic acid, and brevetoxin (Burek et al. 2008, S130; Fire et al. 2008, 832; Forcada et al. 1999, 257), and have been implicated in several large-scale dolphin mortalities in the United States (Fire et al. 2008, 832; Reifel et al. 2002, 276). In the Gulf of Mexico, the severity and frequency of HAB outbreaks depend on increases in water temperature and nutrient input from the Mississippi River (Vollmer and Rosel 2013, 20). In fact, some of the UMEs occurring in the Gulf of Mexico between 1991 and 2007 have been attributed to HABs, during which time higher temperatures and increases in nutrients were observed (19-20). For some areas of the Gulf of Mexico, smaller populations of bottlenose dolphins raise conservation concerns regarding HAB outbreaks (19-20). A particular area of concern is around the Florida panhandle, where over the course of 12 years, at least three bottlenose dolphin UMEs directly attributed to HABs have occurred, causing the death of hundreds of individuals (19-20). One of these UMEs occurred from 1999-2000, during which time 120 inidivduals died (McFee et al. 2006, 199).

HABs, including the red tide toxin *Karenia brevis*, affect Florida's Gulf Coast almost annually and have been linked to marine animal mortality events (Twiner et al. 2011; Fire et al. 2008, 283; Fire et al. 2008, 832). *K. brevis* is a dinoflagellate that produces potent neurotoxins called brevetoxins (Simeone et al. 2015, 7; Vollmer and Rosel 2013, 19; Fire et al. 2008, 283, Fire et al. 2008, 832; Wallace and Clark 1999, 31), which are heat-stable, lipid-soluble, polyether compounds (Twiner et al. 2011) that can kill and/or bioaccumulate in marine organisms (Vollmer and Rosel 2013, 19; Fire et al. 2008, 283). Negative impacts of *K. brevis* blooms include respiratory irritation, shellfish poisoning, and water discoloration (Fire et al. 2008, 284). The brevetoxins also have negative effects on neurological function by binding to voltage-gated sodium channels in neuron cells (Twiner et al. 2011; Fire et al. 2008, 832). It has also been observed that brevetoxins can affect the lungs, liver, and lymphoid tissues, suggesting that they, at least in part, can be aerosolized and inhaled by mammals (Pyenson et al. 2014, 7; Twiner et al. 2011; Fire et al. 2008, 840).

Studies examining the effects of red tide blooms on bottlenose dolphins have investigated large-scale dolphin mortalities to see whether the brevetoxins are the cause or a factor in the dolphin strandings, but findings have been inconclusive (Fire et al. 2008, 284). Previous dolphin mortality events have suggested *K. brevis* as the cause of death, but morbillivirus infections, high tissue concentrations of POPs, and a lack of prey fish coincided with the bloom, so a definitive cause of death could not be determined. In a large-scale dolphin mortality event in the Florida panhandle between 1999 and 2000, a

K. brevis bloom coincided with over 120 dolphin deaths, but carcass decomposition prevented a definitive diagnosis on cause of death, and stomach contents were not investigated for the presence of brevetoxins that might have accumulated through the food chain (Fire et al. 2008, 284).

A comprehensive understanding of trophic transfer of brevetoxins is lacking, but it is clear that finfish and certain types of seagrasses such as *Thalassia testudinum* can accumulate or be associated with brevetoxins and may play a major role in UMEs of marine mammals (Twiner et al. 2011). Bottlenose dolphins found in red tide areas usually do not feed directly on *K. brevis* (Fire et al. 2008, 284). Dolphin exposure to brevetoxins is likely dependent on a variety of factors, including varying concentrations of brevetoxins found in prey species, each with different feeding habits themselves and thus different exposures and accumulations of the toxins (284). There is growing evidence that prey fish act as a vector for brevetoxins to dolphins found in the Gulf of Mexico (Pyenson et al. 2014, 7; Twiner et al. 2011; Fire et al. 2008, 284; Fire et al. 2008, 832), as described in a 2004 dolphin mortality event in the Florida panhandle in which 107 dolphins were found dead (Twiner et al. 2011; Fire et al. 2008, 284). All dolphins sampled had brevetoxins in their system from eating prey species (Twiner et al. 2011; Fire et al. 2008, 284).

Fire et al. (2008, 287) analyzed the level of brevetoxins in prey fish of Sarasota, Florida bottlenose dolphins and found that brevetoxins were present in 100 percent of sampled mullet, pigfish, and spot, and 93 percent of pinfish. In total, 97 percent of all primary prey fish collected during *K. brevis* blooms were positive for brevetoxins in at least one sample or tissue type (287). Omnivorous and piscivorous prey fish may accumulate brevetoxins through indirect trophic transfer (Twiner et al. 2011; Fire et al. 2008, 292). These types of fish accumulate moderate to high concentrations of brevetoxin in their tissues, particularly in the liver tissues of piscivorous fish such as red snapper. Pinfish and croakers accumulate brevetoxins through the ingestion of contaminated shellfish. Organisms feeding on, living with, or associated with seasgrasses may also be susceptible to brevetoxin contamination as seagrasses are known to accumulate brevetoxins as well (Twiner et al. 2011; Fire et al. 2008, 292).

Sarasota Bay dolphins may be particularly vulnerable to HABs as they are repeatedly exposed to them and the toxins produced from such events (Vollmer and Rosel 2013, 19). Therefore, there is the potential of chronic effects from exposure to HAB toxins in Sarasota Bay bottlenose dolphins (19). The presence of multiple toxins may result in immunosuppression, which in turn can lead to secondary stressors that ultimately lead to death (Simeone et al. 2015, 7; Twiner et al. 2011).

Another HAB of concern includes the diatom of the genus *Pseudo-nitzschia*, which produces the toxin domoic acid (Twiner et al. 2011; de la Riva et al. 2009, 109; Reifel et al. 2002, 286). *Pseudo-nitzschia* spp. can bloom and produce domoic acid in a variety of environmental conditions, and the amount of the toxin produced depends on the strain and the bloom itself (de la Riva et al. 2009, 110). Findings by de la Riva et al. (2009, 117) showed a strong correlation between strandings of bottlenose dolphins and *Pseudo-nitzschia* blooms. Strandings tended to occur at the same time or soon after the peak of the bloom, and continued to occur even after the bloom was over. Domoic acid is a neurotoxin that can cause large-scale mortality in cetaceans (Twiner et al. 2011). It is a water soluble amino acid that affects receptors in the brain, causing massive depolarization of neurons with an increase in intracellular calcium ions, energy depletion, cellular swelling, and cell death in the neurons of the brain (de la Riva et al. 2009, 110). It affects the central nervous system rather rapidly and severely and manifests itself through disorientation and difficulty in swimming (de la Riva et al. 2009, 110; Reifel et al. 2002, 286), as well as through seizures and head weaving from severe neurologic disease, reproductive failure, and death (de la Riva et al. 2009, 109-110). Because the effects of domoic acid are acute, dolphins that strand are usually in good body condition, suggesting they had the ability to forage until close to the time of the stranding (109). Domoic acid is transferred to organisms higher on the food chain through trophic transfer from zooplankton (Twiner et al. 2011; de la Riva et al. 2009, 110; Reifel et al. 2002, 286) to mollusks, krill, and planktivorous fish (de la Riva et al. 2009, 110).

Conclusion

The conclusion for this capstone is that the majority of all bottlenose dolphin strandings are due to an unknown cause. This decision is based on previous studies as well as research and analyses conducted. A great deal of those strandings that have a known cause are due to diseases, especially morbillivirus. However, a commonality among all categories of strandings researched is the presence of immunosuppressants such as POPs, heavy metals, and HABs. Many diseases have been known to suppress the immune system as well, allowing for more diseases to enter the body or allowing for parasites to take over the body. Immunosuppressants that can lead to diseases or lead to more diseases tend to be the most common reason or at least a factor for why bottlenose dolphins strand. Therefore, the belief is that immunosuppressants affecting these species should be further studied and thought of as one of the top reasons for strandings.

Because bottlenose dolphins are highly social animals and they tend to socialize with different individuals in a pod under varying circumstances, a disease would have the ability to affect all or most of the animals in the pod as sick individuals come into contact with healthy dolphins. If the dolphins already have a compromised immune system due to immunosuppressants, then that makes it much easier for diseases to infect the dolphins and make the animals very sick. As more and more individuals in the pod become sick, the likelihood of a mass stranding becomes greater as illness is related to stranding probability.

It seems that there is no specific time of year that strandings happen, although a commonality among most of the literature included the spring and summer months. The high occurrence rate of strandings during this time of the year may be attributed to females giving birth during this time. Females would be feeding more often in order to provide milk to their offspring. In doing so, they have a higher chance of ingesting immunosuppressants or would be ingesting a higher concentration of those pollutants. Females would also be expelling about 80 percent of their pollutant burden to their offspring, leaving the offspring susceptible to the effects of these immunosuppressants. The offspring, in turn, would become more susceptible to diseases, not only due to their compromised immune system, but also due to the fact that they have little immunity to diseases already found in the environment. The offspring could pass off the diseases to their mothers who could pass them off to other members of the pod, eventually making several dolphins sick. This would greatly increase the chances of a stranding event occurring.

The analyzed data in this capstone from FWC and McFee and Lipscomb (2009) covers bottlenose dolphin strandings along the southeastern U.S. coast during 18 of the last 23 years. The data has the ability to report how the causes of bottlenose dolphin strandings have changed in the last 23 years. Over time one would think that as technology improved, the ability to detect the cause of a stranding would have improved. However, over time more and more strandings were due to an unknown cause. There is a possible explanation for this greater occurrence of unknown stranding causes over time. The majority of the unknown causes came from the FWC data whereas the other data was collected in North Carolina. Florida is very humid during most of the year and has high air and water temperatures, which could cause rapid decomposition of the body as it sits in the sun. By the time a stranding response team could get information on the deceased animal, the natural weather patterns could make it impossible to determine a cause of death compared to data collected in cooler climates. The majority of the known causes of strandings from the FWC data were due to morbillivirus, which as the literature shows is a major factor in stranding occurrences not only among dolphins, but among other cetaceans as well. The literature also explains that pollutants that act as immunosuppressants can significantly increase the susceptibility of bottlenose dolphins to morbillivirus and that morbillivirus itself can also increase the susceptibility of the dolphins to other diseases and parasites.

The greatest percentage of known causes of strandings from the McFee and Lipscomb (2009) data was due to human-induced causes due to fishery interactions. This could mean both as bycatch and from marine debris. As the literature states, marine debris through either ingestion or entanglement is a serious problem concerning bottlenose dolphins and other marine mammals. Ghost gear and discarded fishing lines and ropes pose a serious health risk to these animals and are increasingly becoming more of a problem. Even with tighter regulations on the fishing industry and the invention of more biodegradable fishing gear, fishery interactions through marine debris still pose a threat to bottlenose dolphins and other marine life. The third most common reason for strandings in the McFee and Lipscomb (2009) data was due to bacterial infections. Based off of the literature, diseases of all kinds greatly increase the possibility of stranding. Diseases were a common theme among the literature as immunosuppressing pollutants in the marine environment greatly increase the chance of bottlenose dolphins succumbing to diseases, which in turn greatly increases the chance of secondary infections and the possibility of stranding.

The literary analysis poses a serious environmental concern regarding the health and stranding occurrences of bottlenose dolphins and other marine life. Chemical or biological anthropogenic agents found in the marine environment seemed to be a leading cause or the catalyst for stranding occurrences of bottlenose dolphins. These pollutants not only cause serious damage to the body themselves, but they can also suppress the immune system, allowing diseases to enter the body and further suppress the immune system, eventually causing the stranding. Immunosuppressants such as POPs, OCs, and marine debris are only increasing in the environment as the human population increases. Although the production of many POPs has been banned in several parts of the world, there are still a great many places that use these chemicals in manufacturing. Even naturaly occurring biological processes such as algal blooms are increasing due to agricultural runoff which increases with a growing human population (Vollmer and Rosel 2013, 19-20; Zagzebski et al. 2006, 334; Deem et al. 2001, 1225; Harwood 2001, 635; Young 1994, 415).

The occurrence of diseases is also increasing in the marine environment due to human population growth. Some diseases are emerging as new vectors are finding their way to the ocean through sewage or wastewater treatment plants as well as through the effects of climate change. Humans are also increasing the severity of diseases as well as the number of emerging diseases through antimicrobial resistance. Humans are taking more over-the-counter drugs, which in turn get excreted and then end up in the ocean, where they are eventually ingested by bottlenose dolphins and other marine mammals. These drugs cause antimicrobial resistance which can increase the severity and persistence of diseases as well as create new diseases, causing more strandings to occur. Future studies should focus on immunosuppressants as a major cause in bottlenose dolphin strandings. Further information would help to clarify the knowledge gaps of what causes bottlenose dolphins to strand. If human population growth continues and nothing is done about these immunosuppressing pollutants, one will only see a continued increase in bottlenose dolphin strandings as well as strandings of other marine mammals.

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I am extremely grateful. I also had another response from Wayne McFee who attached one of his publications to my email request. The publication proved to be extremely useful in my data analysis and I would like to thank Mr. McFee for his help. I would also like to thank the rest of the Southeast U.S. Marine Mammal Stranding Network for either attempting to help me in my request for data, or wishing me the best of luck in my project when they were unable to help. The correspondence I receieved from many of the stranding network members was very insightful and many of them gave great advice.

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Appendix 1

Table 1: Compiled data used for conducting a Chi-Square goodness of fit test for bottlenose dolphin strandings from FWC off the coast of Jacksonville, FL during the years 2011-2015.

Categories	**Sum of Observed (O)**	**Sum of Expected (E)**	**Sum of O-E**	**Sum of (O-E)²**	**Sum of (O-E)²/E**
Asphyxiation	2	19.2	-17.2	295.84	15.40833333
Blunt Force Trauma	1	19.2	-18.2	331.24	17.25208333
Entanglement	6	19.2	-13.2	174.24	9.075
HI Fisheries	3	19.2	-16.2	262.44	13.66875
Morbillivirus	31	19.2	11.8	139.24	7.252083333
Other Diseases	3	19.2	-16.2	262.44	13.66875
Starvation	1	19.2	-18.2	331.24	17.25208333
Stillborn	2	19.2	-17.2	295.84	15.40833333
Undetermined/ unknown	142	19.2	122.8	15079.84	785.4083333
Grand Total	**191**	**172.8**	**18.2**	**17172.36**	**894.39375**

Table 2: Compiled data used for conducting a Chi-Square goodness of fit test for bottlenose dolphin strandings from McFee and Lipscomb (2009, 5-13) off the coast of South Carolina during the years 1993-2006.

Categories	Sum of Observed (O)	Sum of Expected (E)	Sum of O-E	Sum of (O-E)²	Sum of (O-E)²/E
Infectious disease (agent unknown)	1	7.93	-6.93	48.025	6.056
Infectious disease (bacterial)	19	7.93	11.07	122.545	15.453
Infectious disease (protozoal)	2	7.93	-5.93	35.165	4.434
Infectious disease (verminous & fungal)	1	7.93	-6.93	48.025	6.056
Infectious disease (verminous)	6	7.93	-1.93	3.725	0.470
Infectious disease (viral)	1	7.93	-6.93	48.025	6.056
Noninfectious disease (alimentary obstruction, natural object)	2	7.93	-5.93	35.165	4.434
Noninfectious disease (drowning, cause not evident)	1	7.93	-6.93	48.025	6.056
Noninfectious disease (emaciation)	16	7.93	8.07	65.125	8.212
Noninfectious disease (human induced, alimentary obstruction, man-made object)	1	7.93	-6.93	48.025	6.056
Noninfectious disease (human induced, boat trauma)	11	7.93	3.07	9.425	1.189

Noninfectious disease (human induced, fishery)	23	7.93	15.07	227.105	28.639
Noninfectious disease (neonate)	8	7.93	0.07	0.005	0.001
Noninfectious disease (stingray spine)	7	7.93	-0.93	0.865	0.109
Noninfectious disease (trauma, cause not evident)	7	7.93	-0.93	0.865	0.109
Unknown	21	7.93	13.07	170.825	21.542
Grand Total	**127**	**126.88**	**0.12**	**910.938**	**114.872**

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