EVALUATION OF MORBILLIVIRUS EXPOSURE TO BOTTLENOSE DOLPHINS (*TURSIOPS TRUNCATUS*) FOLLOWING THE DEEPWATER HORIZON OIL SPILL

An Undergraduate Research Scholars Thesis

by

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ABSTRACT

Evaluation of Morbillivirus Exposure to Bottlenose Dolphins (*Tursiops truncatus*) Following the Deepwater Horizon Oil Spill

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Deepwater Horizon (DWH) was the largest offshore oil spill in the petroleum industry's history. For a total of 87 days, approximately 3.19 million gallons of oil and natural gas seeped into the Gulf of Mexico. DWH altered the ecology and biology of the Gulf of Mexico and surrounding areas, including many species of endangered marine life and habitat quality. Following the oil spill in April 2010, an unusual mortality event occurred in the Gulf of Mexico in cetaceans, primarily bottlenose dolphins. Dolphin morbillivirus (DMV) was investigated to cause this event. DMV is a well-recognized paramyxovirus that causes dolphin deaths in the United States from acute viral pneumonia, viral encephalitis, or from fungal or bacterial infections from immunosuppression. Therefore, we aim to determine how the event of oil spills affects the exposure of bottlenose dolphins to morbillivirus. We will conduct thorough literature reviews to obtain the polymerase chain reaction (PCR) and serological analysis data for different age categories in order to develop a model to determine morbillivirus exposure in bottlenose dolphins. We will then use the model to quantify the effects of DWH on the morbillivirus exposure to bottlenose dolphins' population dynamics for the future 30 years.

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CHAPTER I

INTRODUCTION

The Gulf of Mexico is vital to the United States' economy and ecology. Ecologically, the Gulf of Mexico possesses many valuable ecosystem resources and services. Case studies were conducted to highlight the ecosystem services most valuable to the Gulf of Mexico; among these, the regulating service of hazard moderation, specifically storm mitigation, was evaluated. It was found that half of the nation's coastal wetlands are found along the Gulf of Mexico – these habitats provide an abundance of supporting, regulating, provisioning, and cultural services that include but are not limited to maintenance of soil and sediment (shoreline stabilization) and hazard moderation (Barbier et al., 2011; National Academies Press et al., 2013; Shepard et al., 2011). Wetland characteristics have furthermore shown positive correlation with vegetation density, biomass production, and marsh size (National Academies Press et al., 2013; Shepard et al., 2011). Fisheries was also examined in a case study in the Gulf of Mexico. In 2011, shrimp and oyster meat harvested in the Gulf of Mexico was valued at $352 million and $84 million, which accounts for 68% and 64% of U.S. landings, respectively. Furthermore, an average of 23 million fishing trips took place in Gulf States and generated an income of over $5.1 billion (National Academies Press et al., 2013; NOAA, 2013a). Cultural ecosystem services found in the Gulf of Mexico come from certain populations of bottlenose dolphins that reside in close proximity to the shoreline. This species is an ideal subject for observation and recreation from the beach or small watercraft. Dolphin ecotourism is also growing nationally and globally as an industry; aside from financial benefits to operators and communities, these tours offer recreational and educational opportunities that allow patrons to appreciate the species and their conservation (National Academies Press et al., 2013).

The Gulf of Mexico also drives the United States' ocean economy. The Gulf of Mexico region accounts for about 14.3% of the United States total employment, 13.6% of total U.S. wages, and 14.3% GDP of the nation (NOAA, 2017). Of all the regions in the U.S., the Gulf of Mexico contributed the highest amount of gross domestic product in the entire U.S. ocean economy. The economic value in the Gulf of Mexico is most noticeable in the oil and gas industry with extractions offshore. An impact in this region's economy is also made with tourism through deep-sea fishing and diving and the seafood industry (NOAA, 2017).

The Deepwater Horizon (DWH) oil spill in 2010 has impacted the Gulf of Mexico ecologically (Adams et al., 2015; NOAA, 2017; Venn-Watson et al., 2015). Approximately 171 million gallons of oil were released into the Gulf of Mexico, and it's estimated that half of that oil and 100% of the methane gas released from the main well is still trapped deep in the oceans' waters (Adams et al., 2015). With these substances trapped in the waters of the Gulf, many levels and forms of life were affected on the ecosystem level. For example, a coral community located 11 km from the original well site showed more than half of its colonies with damage (Adams et al., 2015). Further studies looked for unknown coral communities that could have been affected by the oil spill and found one community twice as far away as the known site and 50% deeper with damage, thus expanding the range of the impact of the spill. Deep waters of the northern Gulf of Mexico are unique bank habitats called salt domes that harbor the highest known levels of seaweed diversity in the region. These habitats also provided homes to deep-sea shrimps, crabs and lobsters. Prior to the oil spill, 60 species of seaweed were documented; the aftermath left 10 species of seaweed and a consequential decline in crustacean abundance and diversity.

Marine mammals also suffered greatly from DWH. For instance, 170 mammals in the Gulf of Mexico were killed directly from the BP oil spill; however, scientists predict that these carcasses uncovered represent only 2% of the true death toll of marine species, placing the actual amount closer to 5,000 mammals in this unusual mortality event. This data led scientists to state that DWH caused the illnesses that lead to the unusual mortality events and subsequent deaths of marine fauna and flora in the Gulf of Mexico (Adams et al., 2015).

Due to the large contamination area of DWH, as many as 19 species of cetaceans in the Northern Gulf of Mexico were impacted heavily, primarily (87%) the common bottlenose dolphin (*Tursiops truncatus*) when an unexpected mortality event was noticed in 2010 following DWH (Venn-Watson et al., 2015). The event included 1,141 dead and/or stranded bottlenose dolphins (*Tursiops truncatus*) from March 1, 2010 to July 31, 2014 in the Northern Gulf of Mexico (Fisheries, 2013). To put this in perspective, the historical average in the affected region is six strandings per year. One cause of the event was investigated to be exposure to dolphin morbillivirus (DMV) (Fauquier et al., 2017).

Bottlenose dolphins (*Tursiops truncatus*) have a worldwide distribution through tropical and temperate inshore, oceanic, and coastal and shelf waters. The current minimum worldwide estimate of the species is about 600,000, with surveys from the U.S. National Marine Fisheries Services estimating 52,000 dolphins in the Northern Gulf of Mexico (Hammond et al., 2012). While they primarily live along the coastal areas of oceans, they are also found offshore around oceanic islands and occasionally even upstream of rivers. They tend to inhabit waters where surface temperatures range between 10°C and 32°C, making the Northern Gulf of Mexico an ideal habitat (Hammond et al, 2012). The coastal and island-centered populations are most vulnerable to habitat degradation, hunting, and incidental catch. It is thought that more anthropogenic events such as oil spills and harmful chemical concentrations are leading to a larger number of unexpected mortalities and longitudinal population decline (Hammond et al., 2012). Currently, the bottlenose dolphin (*Tursiops truncatus*) is listed as Least Concern on the IUCN Red List. However, this does not dismiss the fact that dolphin unusual mortality events are still occurring in the Gulf of Mexico presumably from oil spill effects.

The objectives of this study are to develop an age-structured population dynamics model for the bottlenose dolphin based on published scientific literature, and evaluate the exposure of morbillivirus following DWH that has been hypothesized to be driving the post-2010 population trend in the Gulf of Mexico. The significance of this study is to learn the potential long-term health and environmental effects of oil spills on marine species and ecosystems.

CHAPTER II

METHODS

Focal Species:

Common bottlenose dolphins (*Tursiops truncatus*) are among three species of bottlenose dolphins of the genus *Tursiops*. Bottlenose dolphins are the largest species of beaked dolphins weighing in at 340-400 pounds. The genus *Tursiops* is made distinguishable by a short, snout about 3 inches long. Bottlenose dolphins are distinctly social that often travel in groups of up to 12 individuals. They typically do not migrate but travel fairly far away from home waters to locate waters of a more preferred temperature. Common bottlenose dolphins (*Tursiops truncatus*) are found in temperate and tropical waters of the Pacific and Atlantic Oceans; they migrate as far north and west as North Carolina and California, respectively (MarineBio, 2013).

Bottlenose dolphins are apex predators in the Gulf of Mexico's food web and thereby have an effect on the flow of energy and nutrients throughout the ecosystem (National Academies Press, 2013). They're commonly associated with other cetaceans including both large whales and other species of dolphins, sometimes with mixed schools (Hammond et al., 2012). In the wild, bottlenose dolphins consume a variety of prey species including fish, squid and eels. They often hunt as a team by herding small fishes onto mudflats and jumping out of the water to capture their prey. Generally, bottlenose dolphins consume about 15 pounds of seafood daily (MarineBio, 2013).

Research Area:

The climate of the Gulf of Mexico varies from tropical to subtropical with hurricanes often entering and making landfall on Gulf States. Sea surface temperatures vary between 64 degrees Fahrenheit in the northern Gulf of Mexico and 76 degrees Fahrenheit near the Yucatan Peninsula. During summer months, surface temperatures have been recorded as high as 90 degrees Fahrenheit. Rainfall is present throughout the year and is evenly distributed between the seasons but is often more concentrated during the summer and fall seasons. Being at such a low-latitude and in close proximity to the equator, the climate tends to be generally warm and humid (Biasutti et al.) (Figure 1).

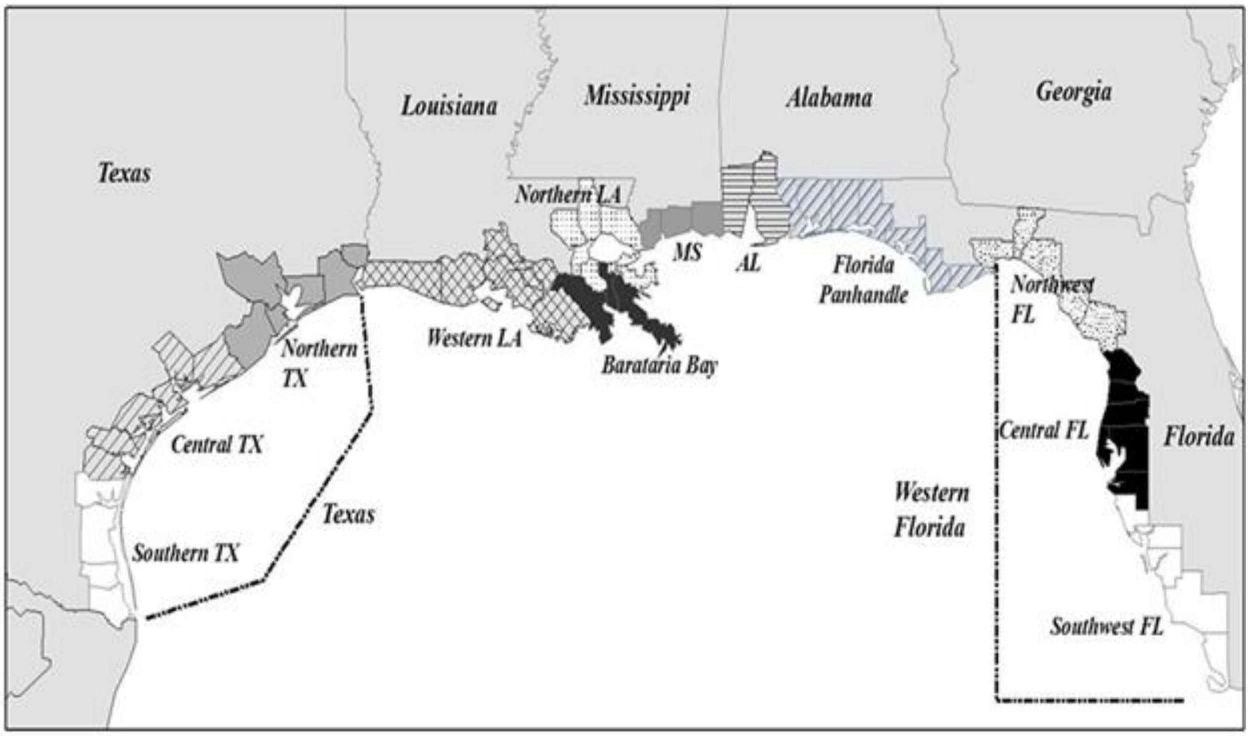

Figure 1. Research area of bottlenose dolphins during 2010-2013 unusual mortality event.

Model Description:

The model, which represents the population dynamics of the common bottlenose dolphin (*Tursiops truncatus)* with exposure to dolphin morbillivirus (DMV) following the Deepwater Horizon (DWH) oil spill in the Gulf of Mexico, consists of parameters that measure the population size of the bottlenose dolphins from age classes 1 to 35 with the mortality rate of dolphin morbillivirus taken into consideration (Figure 2). The model was formulated as an age-structured compartment model. Simulations were run using STELLA® 7.0.1.

All age class population sizes (A) were estimated from Stolen and Barlow, 2003 (Table 1) and were further parameterized with dolphin recruitment before age class 1 (A1):

(1) Recruitment (R) = # of children*Fertile Population*0.5

where the number of children (#) was estimated from literature reviews to be one calf every three years (1/3) on average (Rossi et al., 2017). The fertile population (FP) was estimated from literature reviews to be from age 5 to age 20 in sexually mature bottlenose dolphins; these age classes were summed up and halved to represent the fertile female population of bottlenose dolphins.

Mortality rates from each class were calculated by:

(2) M = A-S

where A is the initial population in the age class and S is the number of individuals that survived from the first age class to the following age class.

Survival from one age class to the next (S) was calculated using the DMV Scenarios and survival rates estimated from Table 1:

(3) S = (A-SR)*(1-DMV)

where A is the age class. SR is the survival rate estimated from Table 1:

(4) $SR = l_{x+1}/l_x$

The effects of dolphin morbillivirus are parameterized with the equation (1-DMV) where DMV comes from DMV Scenarios. There are two cases of scenarios listed in the model: (1) Without DMV and (2) With DMV:

(5) DMV = If (DMV_scenarios = 1) then (0) Else (0.1)

If the scenario does not show effects of dolphin morbillivirus, then the model uses scenario one; otherwise, the effects are present and the model uses scenario two. In the model, the effects of the virus are estimated to be 10% (0.1) mortality due to lack of research on the mortality rates of dolphin morbillivirus following DWH.

To gain a stochastic model, the 10% DMV rates were applied once per 10 years, twice per 10 years (20% DMV rates) and three times per 10 years (30% DMV rates) to simulate outside variables not tested and the possibility of oil spills occurring more than once per 10 years. 10 replicate trials were also run to show variability of random factors in the stochastic model.

Age class (x)	# of dolphins	n_x	Survivorship from x to x+1
0	36	1,000	0.836
1	14	836	0.925
2	32	773	0.811
3	15	627	0.892
4	13	559	0.894
5	8	500	0.928
6	4	464	0.959
7	5	445	0.951
8	3	423	0.967
9	3	409	0.966
10	2	395	0.977
11	3	386	0.966
12	3	373	0.962
13	6	359	0.925
14	3	332	0.958
15	8	318	0.792
16	5	282	0.918
17	5	259	0.911
18	8	236	0.847
19	3	200	0.930
20	11	186	0.731
21	4	136	0.868
22	1	118	0.966
23	4	114	0.833
24	3	95	0.863
25	3	82	0.829
26	6	68	0.603
27	2	41	0.780
28	1	32	0.844
29	2	27	0.667
30	0	18	1.00
31	1	18	0.778
32	0	14	1.00
33	1	14	0.643
34	0	9	1.00
35	2	9	-

Table 1. Demographics of male and female bottlenose dolphins derived from Stolen and Barlow, 2003.

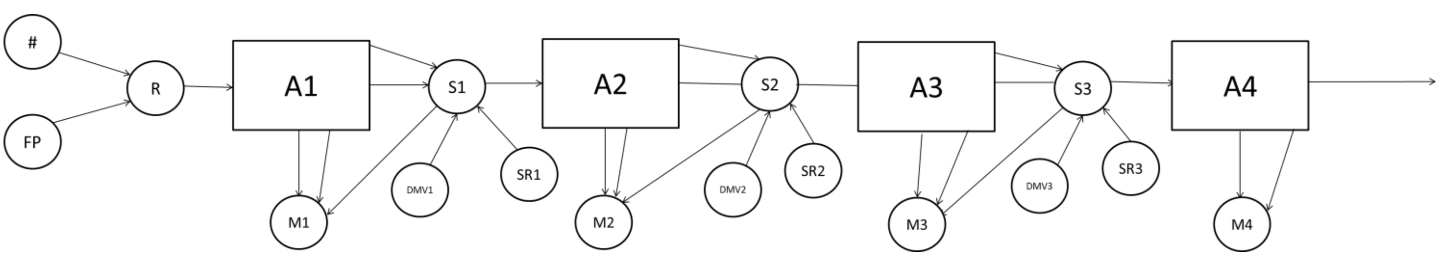

Figure 2. A conceptual model illustrating the bottlenose dolphin population dynamics from age class 1 to age class 35 in the Gulf of Mexico with DMV exposure following DWH.

CHAPTER III

RESULTS

The model we developed was used to run four different scenarios based on the information acquired throughout the duration of this project. All four scenarios used population demographics of the bottlenose dolphin from Stolen and Barlow, 2003, represented in Table 1. One scenario that we tested was a baseline population which ran without any presence of DMV in the bottlenose dolphin population in the Gulf of Mexico following DWH (Figure 3). The second scenario ran estimated the effects of DMV with a 10% mortality rate once per 10 years on 10 replicates, allowing variability for a stochastic simulation to be created (Figure 4). The third scenario ran estimated DMV's effects with 10% mortality twice per 10 years (20%) on 10 replicates (Figure 5). The final scenario ran estimated the effects of DMV on the population with 10% mortality three times per 10 years (30%) on 10 replicates (Figure 7). All DMV scenarios were graphed against the baseline population to compare population trends with and without the presence of DMV.

The results of the baseline model (Figure 3) without dolphin morbillivirus effects show a slight increase in the population size from 218 to 262 individuals within 30 years. Throughout the 30 year prediction of the model, it can be seen that there is a great deal of variability even between replicates in the same scenario of DMV rates. However, all age classes gained a negative trend after applying the different DMV mortality rate percentages, implying the possibility of endangering the population's current conservation status. The graph with 30% DMV shows the most intense decrease of up to 72.07%, but even the lower percentages of DMV (10% and 20%) show significant population declines up to 25.84% and 39.22%, respectively.

Stochastic variability was input into the model to demonstrate the possibility of oil spills occurring more than once per 10 years, as well as to model environmental and various other effects found in nature that could affect the population dynamics of the bottlenose dolphin that were not studied in this project.

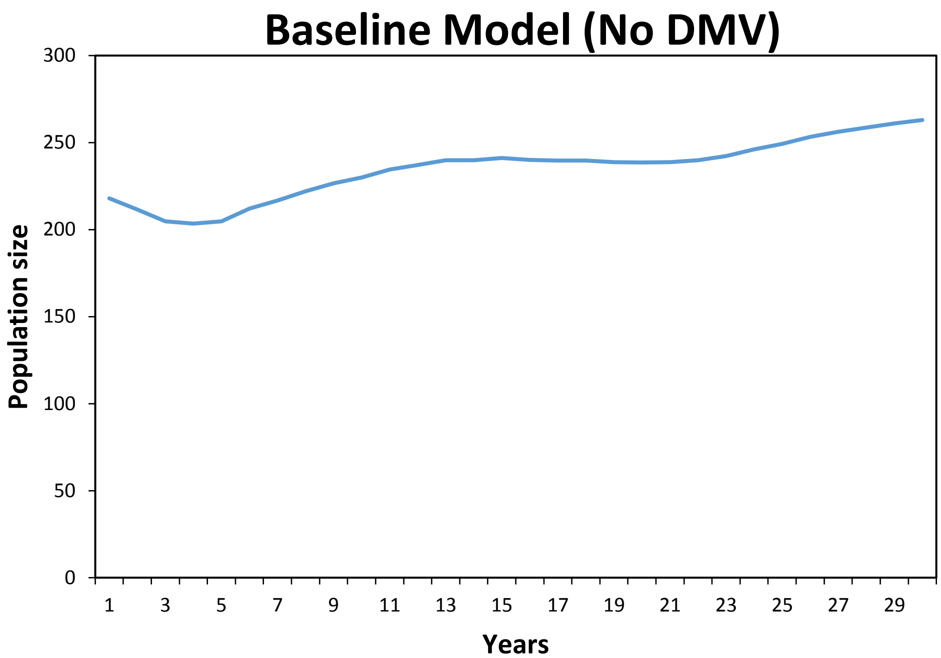

Figure 3. Graph of the baseline run with no DMV presence.

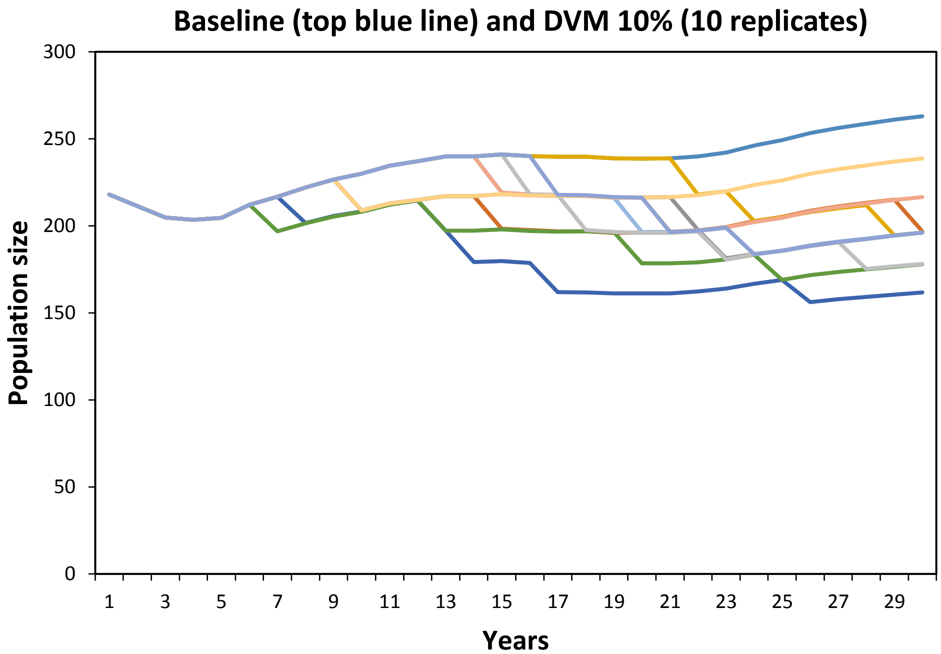

Figure 4. Graph of stochastic model run of 10 replicates with 10% DMV rates per 10 years.

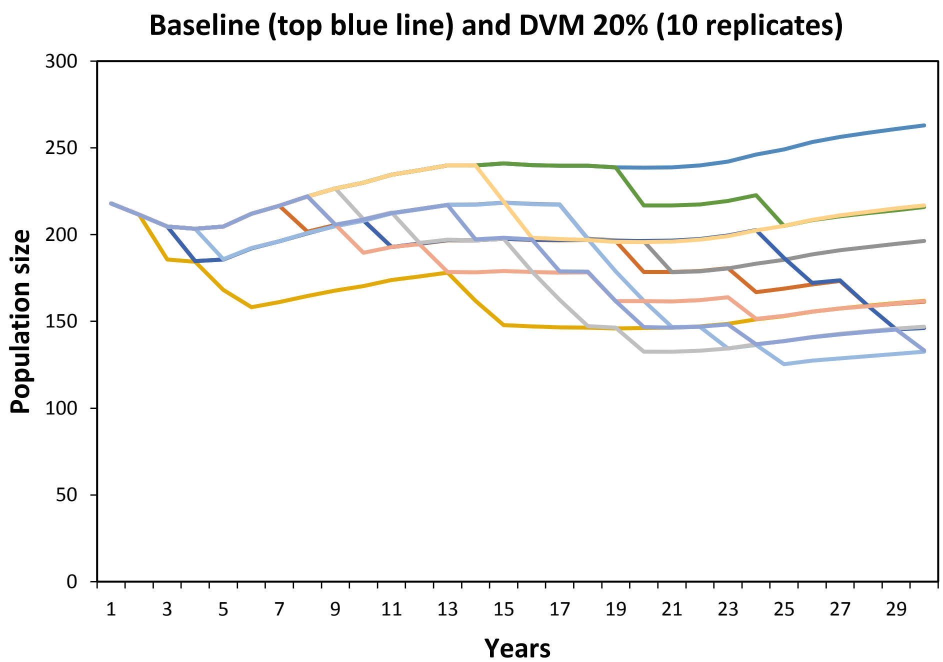

Figure 5. Graph of stochastic model run of 10 replicates with 10% DMV twice per 10 years (20%).

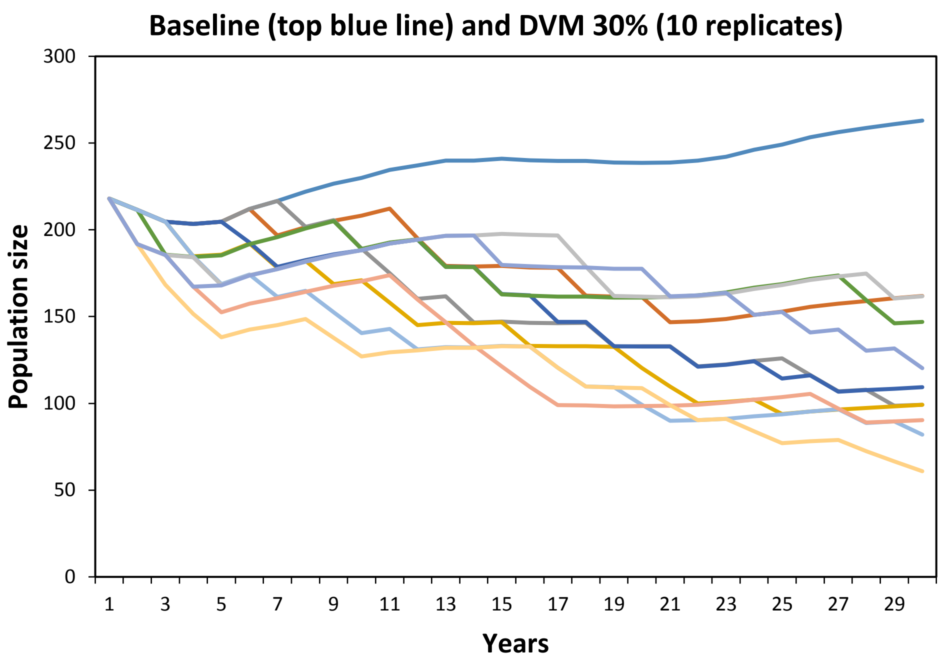

Figure 6. Graph of stochastic model run of 10 replicates with 10% DMV rates three times per 10 years (30%).

CHAPTER IV

CONCLUSION

While the bottlenose dolphin is not listed as endangered, vulnerable or threatened on the IUCN Red List, this should not divert conservationist's effortsand attention away from protecting this species along the coast of the United States. Since the Deepwater Horizon oil spill in 2010, stricter laws and regulations have been placed on oil rigs and their corresponding companies in order to prevent future oil spills from occurring offshore. Through this population model, we have discovered that the impacts of DMV related to oil spills can have a tragic effect on the bottlenose dolphin populations in areas surrounding oil spill sites. With the model, it was predicted that the population would decrease about 72% over 30 years if DMV rates were 30% over that time span. This was the largest fluctuation seen in the four scenarios modeled in this project; however, smaller DMV rates of 10% and 20% were also found to be very harmful to the population with decreases of 26% and 39% of the entire population, respectively.

This research and the results found within it can be used to establish more laws and regulations on offshore oil rigs, do further research on the connection between oil and DMV presence, and do research to possibly find a vaccination/cure for DMV to eliminate the virus from the population entirely. It is also important to continue educating the public on why bottlenose dolphins are important to the Gulf of Mexico's ecosystem and economy. Educating the public is the most effective way to continue the protection and conservation of this amazing species and its ecosystem. With the knowledge that oil spills are a major factor causing dolphin unusual mortality events and the spread of DMV, new ways to conserve the bottlenose dolphin in the Gulf of Mexico and around the world can be implemented.

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