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The Effect of Boat Type on Bottlenose Dolphin (*Tursiops trucatus*) Behavior in the Mississippi Sound

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THE EFFECT OF BOAT TYPE ON BOTTLENOSE DOLPHIN (*TURSIOPS TRUNCATUS*) BEHAVIOR IN THE MISSISSIPPI SOUND

by

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ABSTRACT

THE EFFECT OF BOAT TYPE ON BOTTLENOSE DOLPHIN (TURSIOPS TRUNCATUS) BEHAVIOR IN THE MISSISSIPPI SOUND

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Increases in oceanic shipping are a global phenomenon, and a leading cause of concern for marine animal welfare. While it may be difficult to assess the effect of boat traffic on all species in all contexts, it is vital to report anthropogenic impacts where longitudinal data is available, and doubly so where a dearth of information exists. The purpose of this study is to describe how dolphin behavior changed in the presence of boats in the Mississippi Sound between 2006 and 2012, and more specifically, to detail how different boat types impacted dolphins' behavioral states. This study is unique in its capacity to assess the effect of all major boat types in a given area. Common boat types in the Mississippi Sound were operationally defined as sailboats, recreational boats, fishing boats, shrimp boats, shipping boats, ferries, or patrol boats. Behaviors were grouped into nine behavioral states including feed, social, travel, mill, with boat, rest, other, underwater, and not found. Behavioral states were recorded via an instantaneous scan sampling method. Mixed multivariate analysis of covariance (MANCOVA) tests determined that there was no statistical difference between behavioral states before and after boat events, when boat types were collapsed. However, when boat types were included in analysis, they affected dolphin behavior in significantly different ways. This thesis contributes to the field of difficult-to-assess indirect effects of boat traffic, and

provides incentive for researchers to perform inclusive boat traffic surveys in future studies.

ACKNOWLEDGMENTS

"Sometimes you go through things that seem huge at the time, like a mysterious glowing cloud devouring your entire community" (Fink & Cranor, 2012). Heidi, thank you for not only stepping up as chair of my committee, but also for standing up as a woman of science. You are a fabulous human being, a glowing ember on a mountain of coal, and I am so glad to have you as an advisor. Stan, without you, this data set quite literally would not exist, and I would not be at USM studying marine beasties if you did not invite me into your Marine Mammal Behavior and Cognition Lab. Thank you for the kind words, constructive criticism, and socially-acceptable fist-bumps that look like octopi. Dr. Frank and Dr. Moore, thank you for taking the time to be a part of this committee. To my lovely lady lab mates, past and present: thank you for the feedback, the comradery, and for following your dreams. You are some of the best (mer-)folk out there, and I can't wait to see all the wonderful things you accomplish. To my family and those long-distance-yet-beloved: thank you for being patient with me. Tyler, thank you for everything and more.

DEDICATION

Marine life of the Mississippi Sound, this one's for you. You've had a hard run of it so far, and I hope you continue to endure. Environmental Protection Act, thank you for caring about the well-being of marine animals, and your commitment to keeping dolphin populations at sustainable levels. I hope your ruling agency will continue to feel the same way.

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USM	The University of Southern Mississippi
MSWDP	Mississippi Sound Wild Dolphin Project
MANCOVA	Multivariate Analysis of Covariance

CHAPTER I - INTRODUCTION

Motorized transportation and recreational activities have increased over the past several years in both terrestrial and aquatic environments (Buckstaff, 2004). Notably, there have been dramatic increases in aquatic eco-tourism (Constantine, Brunton, & Dennis, 2004; Erbe, 2002; Foote, Osborne, & Hoelzel, 2004; Lusseau, 2005), large ship presence (Erbe, MacGillivray, & Williams, 2012), and global shipping (Hildebrand, 2009). The shipping industry has expanded with the rise in human population and the drive to globalize, while the rapid increase in the eco-tourism industry may be in part due to newfound profitability; its net worth was conservatively estimated at one billion dollars (Constantine et al., 2004). Data taken from the near-shore waters of Washington state demonstrates this change: fewer than 20 active commercial shipping boats were observed per year before 1991, but this number increased to nearly 80 by 2002 (Foote et al., 2004). The same authors estimated that less than five boats per year actively followed marine mammals before 1991, and just six years later this number increased to 20. Similar results were found in the Haro Strait, where orcas were on average exposed to a large boat every hour, every day, year-round in 2008 (Erbe et al., 2012). Likewise, a resident community of dolphins was reportedly exposed to boats within 100 meters (m) every six minutes in Florida's Gulf Coast (Buckstaff, 2004).

Boat Presence as a Social Issue

Boat presence is associated with many risks for marine mammals, a governmentally mandated issue for Americans beginning in 1972 with the creation of the Marine Mammal Protection Act (MMPA). The United States congress was encouraged to pass the MMPA when by-catch resulting in the incidental mortality of dolphins in the

1960s spurred public outcry (Hofman, 2008). The MMPA confirms society's interest in marine mammal welfare, and demonstrates the commitment of this country to maintaining marine mammal stocks at their optimum sustainable populations in order to uphold their ecological role (Roman et al., 2013). As upper trophic level predators, dolphins play a critical part in structuring their ecosystem (Roman et al., 2013). Because of this, if a local population of dolphins were displaced from their habitat, there would be consequences for the biodiversity and condition of the environment they inhabit, including the Mississippi Sound.

Conservation Efforts

Because of the ecological importance of dolphins and the implementation of the MMPA, governmental, non-governmental (NGO), and private organizations have grown increasingly more interested in marine mammal conservation, especially in the form of 'dolphin-safe' fishing practices. Hall and Mainprize (2005, p. 135) defined by-catch as the "fishing mortality resulting from the catch that is not accounted for in the landed catch," which often includes marine mammals caught while targeting the same schools of fish. They researched and discussed measures that need to be taken in order to reduce global by-catch by 25-64%, which included the minimum modifications necessary for improvement of fishing gear. Additionally, they reviewed other methodologies that have attempted to curb by-catch. For example, the use of pingers and other acoustic deterrents have been used to prevent dolphin entanglement in drift nets (Gazo, Gonzalvo, & Aguilar, 2008).

The public's awareness and desire to contribute to dolphin conservation has been enhanced by private organizations like the Audubon Society and he Monterey Bay

Aquarium. These organizations provide free, user-friendly, wallet-sized guides (i.e. ‘Seafood Lovers Guide’ and ‘Seafood Watch’) that help the public identify species of fish that meet or fail by-catch criteria so they can in turn support the companies that harvest fish sustainably from the convenience of their restaurant or supermarket (Hall & Mainprize, 2005). Additionally, in the 1990s ‘dolphin-safe’ food labeling became a popular way to notify the public that purchased fish were not captured using the ‘dolphin set’ method, which was characterized by targeting dolphins to capture tuna. The U.S. government even imposed import embargoes on other nations that failed to adhere to these standards in the labeling system (Hall & Mainprize, 2005).

Risks

Despite conservation efforts, risks to the wellbeing of marine mammals including direct effects (e.g., injury or death by collision or by-catch), and indirect effects (e.g., noise pollution, habitat displacement, and disruption of important behaviors) are linked to boat presence. While the Marine Mammal Protection Act (MMPA) sets the stage for governmental support for wild cetacean conservation and research on marine mammal welfare, it has been relatively ineffective in treating indirect impacts (Roman et al., 2013). One potential reason for this may be that “indirect effects are more difficult to evaluate” (Nowacek, Wells, & Solow, 2001). As such, the effect of boat presence on dolphin behavior and wellbeing are far from being fully understood. Since these artifacts have the possibility to impair physiology, acoustic ability, communication, and social interaction in dolphin populations, more research is needed to discern which aspects of boat presence impact dolphin behavior, and correspondingly, their role as a major ecological predator in their environment.

Risk of Physical Injury. Bottlenose dolphins are one of many marine mammal species that have numerous documented injuries as a direct result of boat presence, be it intentional or accidental. As previously mentioned, fishing practices with ‘dolphin set’ techniques track and sacrifice dolphins in order to haul profitable, commercial fish species (Hall & Mainprize, 2005). However, since more sustainable fishing practices are currently encouraged, accidental collision of marine mammals is of rising concern. A study in Perth, Australia empirically tested the assumption that by feeding wild animals, humans do more harm than good (Donaldson, Finn, & Calver, 2010). As predicted, Donaldson et al. reported a higher occurrence of boat strike and fishing line entanglement with dolphins that had been conditioned to take food from humans compared to those who were not. This problem is not limited to previously fed dolphins, and even extends to other species. Although dolphins are faster than manatees, they often inhabit the same environment, and it is worth noting that as a direct result of motorboat collisions, the probability of the manatee’s survival as a species remains uncertain (Solomon, Corey-Luse, & Halvorsen, 2004). Similarly, with increasing numbers of boats in the same locations, scientists speculate that this could be a serious concern for the future of bottlenose dolphins as well (Wells & Scott, 1997).

Risk of Noise Pollution. Commercial shipping has contributed to the increase of ambient noise across ocean basins by as much as 12 dB (Hildebrand, 2009). While there are many sources of ambient noise in the ocean, longitudinal data (1994-2007) shows dramatic increases in amplitude over specific spectral bands (16-100 Hz) used primarily by ships (Andrew, Howe, & Mercer, 2011). The noise generated by boat traffic impacts the ocean soundscape even more than seismic surveys or military sonar, and has recently been labeled a pervasive threat to entire marine ecosystems worldwide (Williams, Erbe, Ashe, Beerman, & Smith, 2014; Williams et al., 2015). This is particularly troubling for dolphins, whose most vital sensory modality is their acoustic system. It enables navigation though their environment, location of objects or individuals, foraging, and communication. The frequency range of dolphin whistles (4-20 kHz) overlaps with boat noise (0.1-10 kHz), making humanity's increased aquatic activity "the greatest source of anthropogenic noise for bottlenose dolphins" (Buckstaff, 2004, p. 709). The effect of boat noise may result in miscommunication, delays in information reception/processing, and energetic wastefulness.

Many species respond to interfering noise by increasing duration, amplitude, repetition rate, and/or frequency of their signals (Brumm & Slabberkoorn, 2005). Cetaceans are no exception. They can modify their signal amplitude (Holt, Noren, Veirs, Emmons, & Veirs, 2009) or double their whistle repetition rate in response to boat noise (Buckstaff, 2004). A recent study on bottlenose dolphins measured the energetic cost of these types of vocal modifications, and found that metabolic rates were up to 1.5 times higher during vocalization. Longer, louder, and/or more repetitious signals resulted in higher metabolic rates even after the event has concluded (Holt, Noren, Dunkin, & Williams, 2015). Theoretically, a dolphin who doubles their repetition rate would increase their oxygen consumption by 352.2 ml, and would need to replace 7 kJ worth of calories (Holt et al., 2015). Additionally, various behavioral responses to boats (i.e., increased traveling/surface behaviors and decreased foraging) may occur in combination with acoustic modification, and result in an even higher metabolic cost (Holt et al., 2015; Lusseau & Bejder, 2007). If a dolphin is consistently increasing their repetition rate (as well as altering their behavioral budget) due to frequent boats encounters, the metabolic and dietary cost on an individual can prove to be a formidable risk. This is especially true when discussing energetically sensitive individuals, such as those who are malnourished, young, pregnant, or producing milk.

Risk of Habitat Displacement. Between 1999 and 2002, Lusseau (2005) conducted a longitudinal study in Milford Sound, a large eco-tourism destination with more than 8000 dolphin scenic cruise tours per year. Out of the seven fjords this resident population inhabits, this fjord is the most populated. During the summer, Milford Sound's high degree of boat traffic (dotted line, Figure 1) corresponded with resident dolphins spending the least amount of time in this fjord during this season (bold line, Figure 1). Incidentally, when dolphins are in Milford Sound during the summer, they were more likely to be found in the no boat zone. Whereas Lusseau (2005) found Milford Sound to be most utilized in the winter, and infrequently in the summer, the inverse of his results were found previously, as Milford Sound was historically (1968-1970) utilized as a nursery in the summer but rarely used in the winter. He also controlled for environmental factors (e.g., temperature) in order to account for potential alternative reasons for this distribution and eliminate threats to causality. The effects of boat traffic and temperature were analyzed separately and together in order to determine the best-fitting model using Akaike Information Criterion (AIC), which quantified the amount of variation explained by the model, and an AIC difference of 4.08 was enough to indicate that the boat traffic model best predicted residency pattern. Hence, there is evidence that heavy boat traffic may cause changes in demography and result in habitat displacement in bottlenose dolphins.

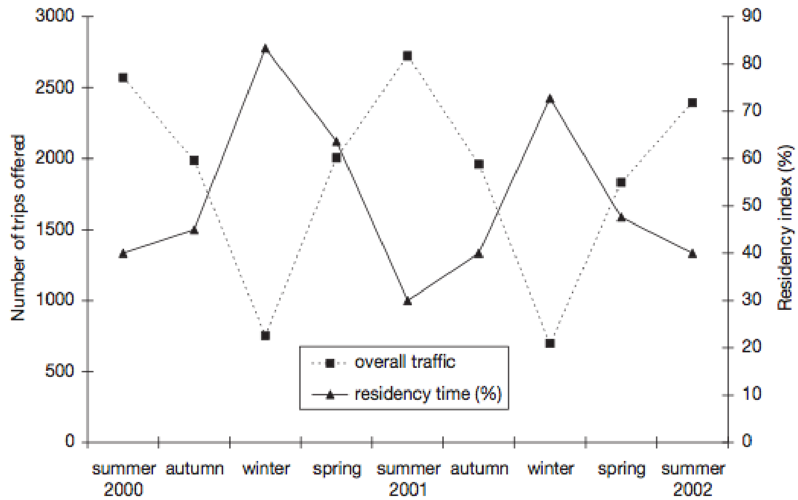

Figure 1. Boat trip versus bottlenose dolphin abundance in Milford Sound.

Relationship between the number of boat trips offered each season and the seasonal residency index of bottlenose dolphins in Milford Sound between December 1999 and February 2002. The residency index is the number of days when dolphins were present in the fjord related to the number of days spent looking for them each season (Figure 3 from Lusseau, 2005).

Risk of Disrupting Activity Budget. Dolphins that do not permanently flee a habitat may only vacate temporarily or may be less sensitive individuals (Bejder, Samuels, Whitehead, & Gales, 2006). These different reactions to boat presence may divide the population into those who will later leave permanently or remain. However, there are long-term costs of remaining near consistent boat traffic. For example, female reproductive success and calf survival rates may plummet and put the population at risk (Bejder, 2005; Lusseau & Bejder, 2007).

Regardless of their long-term strategy, dolphins subject to heavy boat traffic for any amount of time will be constantly disrupted. Heighted cortisol levels (Williams et al., 2014) and a number of other deleterious results accompany these events. As discussed previously, a noisy environment will mask acoustic signals, which will require much more energy to send, and result in a substantial caloric loss (Holt et al., 2015). In these situations, not only are boats interrupting important vocalizations - they are increasing the time needed for foraging. Ironically, boat traffic is the reported cause of the decline in foraging activity in Scotland (by 49%) and Canada (Pirotta, Merchant, Thompson, Barton, & Lusseau, 2015; Williams, Lusseau, & Hammond, 2006). One cause of foraging decline is the dolphins' strategy of boat evasion.

Many cetaceans have been reported to stop normal (baseline) behaviors in favor of avoidance behaviors (e.g., longer dive times, faster speeds, and change in direction) when in the presence of boats. Changing path direction evolved to make anticipated travel patterns less predictable to a predator (or boat). However, when a dolphin is subject to repeated disturbance, more time is spent diving/swimming and there is less time to feed (Williams et al., 2006). This lower caloric intake coupled with excessive energy expenditure is a major cause of concern. Researchers who studied avoidance behaviors in response to boat traffic initially interpreted their minor effect sizes as habituation to the routine one boat per hour, daily, year-round (Williams et al., 2002). However, more recent explanations deem habituation misleading. Instead, more sensitive individuals may simply be driven out of the high-traffic areas, as evidenced by reduced abundance (Bejder et al., 2006). Boat presence may also affect the population's evolutionary trajectory by selecting for bolder individuals (Lusseau & Bejder, 2007).

Constantine et al. (2004) reported on social, forage, rest, travel, and mill behaviors in bottlenose dolphins. They detected a 30% difference in resting behaviors in the presence of permitted and non-permitted vessels (2% and 32% respectably), which they claimed was a meaningful difference that could result in the depletion of fitness, individual reproductive success, and population size. However, they concluded that these impacts could take over 30 years to detect. Miller, Solangi, and Kuczaj (2008) found that passing speedboats most interrupted rest and feeding behaviors, and as a result dolphins showed increases in avoidance behaviors (e.g., increased dive duration and traveling). For example, dolphins that were initially milling/feeding increased traveling behavior by ~37%. Miller et al. (2008) argued that determining a biological effect is difficult when considering short-term responses, but suspected that behavioral short-term changes could predict or represent long-term effects like decreased health, viability, and energy acquisition of a population. Indeed, research from the past two years explains that even non-injurious effects and minor (10-20%) to moderate (20-50%) changes in behavior can produce biologically and ecologically significant effects when consistent disturbance is taken into account (Williams et al., 2014; Williams et al., 2015).

Replication in a Novel Area

There have been very few studies on the effects boat traffic has on the animals that reside in the Mississippi Sound, yet there are more than 304,000 registered boats in the area (Miller et al., 2008). Additionally, bottlenose dolphins in the Mississippi Sound may respond very differently to boat presence in comparison to bottlenose dolphins in New Zealand and other parts of the world (Constantine et al., 2004; Lusseau, 2005). One reason being that dolphins in different places around the globe will have different environmental constraints. Some habitats will be naturally or artificially louder than others. For example, Kaneohe Bay in Hawaii has unusually loud snapping shrimp that are capable of altering the frequency of bottlenose dolphin echolocation clicks (Au, 1993; Au & Banks, 1998). And as previously mentioned, a portion of the maritime territory in the Pacific Northwest and Northern British Colombia has notably high levels of commercial ship noise pollution: at minimum, one large ship is reported to travel through this area per hour, everyday, year-round (Erbe et al., 2012).

As such, even though boat traffic studies have been conducted in Florida, Washington, Australia, New Zealand, Italy, and Turkey, replication is needed in other major dolphin habitats because studies between field sites are variable. Additionally, behavioral states vary between studies, and have not been thoroughly confirmed to be generalizable to the entire species. For example, Constantine et al. (2004) noted that 11% of all behaviors in their study were resting behavior; this result was similar to reports from the Gulf of California in Mexico (8-10%) and other locations in New Zealand (11-12%). However, they admitted that their results from the Bay of Islands, New Zealand, were very different from similar studies conducted in the Shannon Estuary in Ireland (2%) and the Sado Estuary in Portugal (0.2%). This may be due to differences in certain areas' tidal currents (Constantine et al., 2014), temperature, ambient noise, low visibility, unnoticed anthropogenic effects, or other environmental factors.

Gaps in the Literature

Most studies focus on only one boat type, such as large shipping boats (Williams et al., 2006; Williams et al., 2014), recreational boats (Nowacek et al., 2001; Miller et al., 2008), or tour boats (Constantine et al., 2004), to find effects on dolphin behavior. However, as previously mentioned, many of these studies are conducted in different locations all around the globe, which may result in different findings simply because of different country's standards, environmental features, or third variable anthropogenic effects (see replication in a novel area section). For example, Constantine et al. (2004) was not able to compare results from even the same type of boat (tour-boats) across similar studies in different countries. Hence, assuming that behavioral data from different locations are generalizable may lead to erroneous conclusions.

Additionally, many authors avoided attempts to compare results from different boat types at different locations. While some authors ventured to mention frequencies of several boat types in the same location, they did not include them in analysis with behavioral responses. For example, Foote et al. (2004) mentioned the relative frequencies of shipping boats alongside whale-watching boats; however, only the effects of eco-tourism were included in analysis. Alternatively, Hastie, Wilson, Tufft, and Thompson (2003) acknowledged many different boat types in their study on breathing synchrony, but collapsed recreational boats, dolphin-watching vessels, tugboats, oil tankers, and cruise liners together into one variable.

Different boat types have features that may be deleterious to dolphins in different ways. For example, approaching speedboats are very fast. Although the degree of noise pollution they emit is short-lived and not as loud as shipping vessels, speedboats illicit immediate responses from dolphins that directly affect daily activity budgets (Erbe et al., 2012; Miller et al., 2008). Perhaps this can be attributed to the abundance of individual dolphins that have had deleterious prior experiences with speedboats, and any observational learning that occurs from those events (Wells & Scott, 1997). Even short-lasting interactions with recreational vessels, if consistently repeated, have been reported to affect feeding/social behaviors and activity budgets, with potentially dire consequences on dolphin fecundity (Miller et al., 2008).

Lusseau (2005) had similar concerns about tour boats. Although they are slow moving vessels in comparison, he questioned what would happen when the “probability of encountering another boat was so high that a short-term displacement only results in another boat interaction" (Lusseau, 2005, p. 266). He went on to find that dolphins will adapt to the increased boat traffic by avoiding the area altogether. Large commercial ships are also not as fast as speedboats, but they are one of the leading sources of noise pollution in our oceans. Commercial ships produce two layers of frequencies: high frequencies can only be heard nearby, but the more infamous far-reaching low frequencies (<200 Hz) have the capacity to span over entire ocean basins (Hildebrand, 2009). Even though differences between the boat types described above are evident, all three have been independently reported to effect dolphin populations in the same general ways (e.g., reducing foraging and fecundity), and further have been linked to increased physiological stress (Williams et al., 2006; Williams et al., 2014).

Since 2013, a few publications have attempted to analyze more than one boat type in the same location. These studies came to the consensus view that vessel type is an important factor in the behavioral and/or acoustic responses of bottlenose dolphins (Bas, Amaha Öztürk, & Öztürk, 2014; La Manna, Manghi, Pavan, Mascolo, & Sara, 2013). In Turkey, behavioral state reactions (e.g., traveling, diving, surface-feeding, resting and socializing, milling) were used to compare the effects of high-speed boats, fishing boats, ferries, high-speed ferries, and commercial cargo ships over one year (Bas et al., 2014). Of these, high-speed boats and high-speed ferries produced the highest number of negative reactions, while small fishing boats rarely caused any behavioral response. Fast speeds and unpredictable boat routes seemed to be the most influential boat characteristics. Additionally, more than two boats present (regardless of type) resulted in negative responses. Indeed, boat type, speed, distance, and quantity were all individually important factors manipulating dolphin response, but Bas et al. (2014) endorsed using of all four cumulative effects for mitigation purposes.

In Italy, La Manna et al. (2013) compared motorboats (e.g., small recreational boats) to trawlers over two years (2006 and 2009), and found that dolphins were impacted significantly by both boat types but in different ways (La Manna et al., 2013). Motorboat disturbance resulted in habitat displacement (or in 1.8% of the events, complete silence), while trawler disturbance resulted in noise masking and a need to increase acoustic efforts. For example, the whistles in the presence of a trawler were on average longer duration, higher frequency, and over a greater range of frequencies (La Manna et al., 2013).

Until very recently, the literature continuously reiterated the generic answer of survivability without specifying which boat types contributed to which specific ailments or concerns. Bas et al. (2014) and La Manna et al. (2013) exemplify the direction this field needs to take in order to obtain a more holistic and meaningful view of specific populations, study areas, and the requirements needed for local mitigation. This need is emphasized throughout the field of wildlife management, as different types of boats seem to disturb a variety of species (including turtles; Selman, Qualls, & Owen, 2013) in significantly different ways. The limited analysis of more than one common boat type simultaneously, and failing to distinguish different boat type's specific effects, has created a gap in the literature. There is little information regarding the ways which different boat types affect dolphin behaviors over the period of one study (controlling for maturation and seasonality), in one location (controlling for generalizability). Additionally, no studies to date have accomplished this task using longitudinal data from more than two years. To control for the confound of comparisons made between potentially non-generalizable location-specific studies, the proposed study seeks to demonstrate differences in effects between all the common boat types in one area. Hence, behavioral states in response to all observed boat types will be assessed in the Mississippi Sound from 2006 to 2012.

The main objective for this study is to determine the impact of boats on the behaviors of bottlenose dolphins (*Tursiops truncatus*) in the Mississippi Sound. In so doing, this study will address the variety of threats boat traffic poses to marine mammal protection, fill in gaps to the literature regarding differences in boat types, and assess anthropogenic effects in a poorly studied location.

This kind of information will help empirically determine if dolphins discriminate between boat types. The answer to this will affect the way future studies are conducted by either keeping boat types separated, or combing boat types that produce similar results. Additionally, this information will help inform NGOs and the governmental departments about the boat types that should be restricted and in which specific ways.

Hypothesis

Many studies that have demonstrated bottlenose dolphin behavioral response to boat presence are detailed above. The general consensus is that boat presence increases dolphin dive duration, travel time, swimming speed, heading changes, synchronous behaviors, and decreases interanimal distance (Bas et al., 2014; Buckstaff, 2006; Hastie et al., 2003; Miller et al., 2008; Nowacek et al., 2001). General methodology will follow Miller et al. (2008). For example, the same location, behavioral states, and ethograms will be used as in Miller et al. (2008). However, instead of solely measuring the reaction of dolphins passing “high-speed” recreational boats (i.e., speedboats), reactions will be assessed for all major boat types in the area. For consistency, presence of a vessel will be defined as any watercraft that makes a wake within ~100 m of the dolphin focal group (Miller et al., 2008). Miller et al. (2008) assessed behavioral states travel, mill, feed, social, rest, other, and not found from opportunistically gathered data in the Mississippi Sound from 2003 to 2005. The proposed timeline for this study will not overlap with Miller’s data, but will instead complement the previous study by analyzing data collected from 2006 to 2012. Miller et al. (2008) compared the behaviors of dolphins 10 minutes before a speedboat was within ~100 m of the focal group to behaviors of dolphins 10 minutes after a speedboat had passed. The distance parameter of ~100 m from the focal group will remain consistent between studies.

Miller et al. grouped dolphins into two groups when analyzing behavioral states; dolphin groups who were *initially traveling* in baseline/pre-speedboat data had no change in overall behavior after a speedboat passed (Figure 2; Miller et al., 2008). However, dolphin groups who were *initially non-travelling* in baseline/pre-speedboat data showed an increase in traveling and a decrease in feeding behavior after a speedboat had passed (Figure 3; Miller et al., 2008). Since Miller et al. had only two years of data, and only included high-speed recreational boats, only 17 encounters met inclusion criteria (n=17). Even so, Miller et al.’s (2008) data imply that dolphins will increase travel after a high-speed watercraft passes, regardless of their original behavioral state (e.g., traveling, milling, or feeding). Additionally, it highlights *previous behavioral context* as an important factor to consider when analyzing behavioral response data before and after a boat event.

Supported by the numerous boat traffic studies mentioned above, I predict that boat presence has a deleterious effect on the sampled bottlenose dolphin population in the Mississippi Sound, and that this behavioral change will manifest via increases in avoidant behavioral states (e.g., travel, underwater, and not found) relative to contexts where the research vessel is the only one present (hereafter referred to as boat absence). The differences between boat absence (before) and boat presence (after) will be assessed across nine behavioral states.

Additionally, I predict that bottlenose dolphins do not react to all boats equally. The aforementioned avoidance behaviors (e.g., travel, underwater, and not found) are expected to increase in the presence of shipping and recreational vessels. Inversely, feeding behaviors and with-boat behaviors are expected to increase in the presence of certain boat types (e.g., fishing boats). Ultimately this study is explorative, and third variables (e.g., boat speed and distance) will most likely play a factor in the results as well.

CHAPTER II - METHODS

Sample Population

Atlantic bottlenose dolphins (*Tursiops truncatus*) were identified as the upper trophic level predator of interest in the Mississippi Sound. Being a popular model species, bottlenose dolphin behavioral repertoires were well established, even in the presence of boats (see introduction for review). This was beneficial as this study compared the degree of reactionary behavior between boat-mediated contexts (i.e., boat presence and different boat types).

Figure 2. Study Area.

Satellite image of study area in the Mississippi Sound, including Gulfport, Cat Island, and Ship Island (Figure 1 from Miller et al., 2008; included with permission, per. comm. Kuczaj, 2016).

Sample Strategy

Opportunistic boat surveys were collected by the Marine Mammal Behavior and Cognition Laboratory from the University of Southern Mississippi for the “Mississippi Sound Wild Dolphin Project” (MSWDP) from July 2003 to August 2012 in the waters surrounding Gulfport, Cat Island, and Ship Island (Figure 2). The study area spanned approximately 330 square miles. Boat surveys were conducted four times every month for the duration of the MSWDP’s timeline. However, since data collection began to include behavioral states in July 2006, this study only analyzed data from July 2006 to August 2012.

Once dolphins were sighted, the research vessel followed at a suitable distance to obtain data. A pod was defined as all dolphins within 100 m of each other. One researcher began encounters by collecting at least 15 minutes of behavioral data, another researcher took photographs of individual dolphin dorsal fins for identification, and a third researcher recorded environmental data, including the time other watercrafts entered the area within 100 m, boat distance, boat type, and boat speed (Table 1). Behavioral data were collected using a modified instantaneous scan method for behavioral states (Mann, 1999). Behavioral state was determined by the behavior of the majority of the group (Table 2), and was recorded at the beginning of every minute. If dolphins were submerged at the time of behavioral state recording, a one-minute delay was permitted for the dolphins to resurface. If the behavioral state was the same as the previous minute’s behavioral state, then the state did not change and was recorded as the same state for the elapsed minute. However, if the dolphins did not surface during the one-minute delay, or resurfaced engaging in a different behavioral state, then the dolphins were recorded as “not found” for that elapsed minute. Behavioral state definitions were adapted from Shane (1990) and descriptions are listed below (Table 2).

Table 1

Boat Types

Type	Description and Visual Depiction
Sailboats	Any boat with the sail currently up not using the engine. (a) Small: 5-10 ft, (b) Medium: 10-25 ft, (c) Large: more than 25 ft. (a)  (b)  (c) 
Recreational Boats	Any boat with an engine used for motoring, water skiing, sailboats using engines, etc. (a) Small: 5-10 ft, (b) Medium: 10-25 ft, (c) Large: more than 25 ft. (a)  (b)  (c) 
Fishing Boats	Any boat with fishing lines in the water, moving or anchored. (a) Small: 5-10 ft, (b) Medium: 10-25 ft, (c) Large: more than 25 ft. (a)  (b)  (c) 
Shrimp Boats	Always large (more than 25 ft).  
Tugs/ Barges/ Shipping	Always large (more than 25 ft).  
Ferries	Always large (more than 25 ft).  
Patrol Boats	Any boat owned and operated by the U. S. Coast Guard. (a) Small: 5-10 ft, (b) Medium: 10-25 ft, (c) Large: more than 25 ft.

Table 1 (continued).

Patrol Boats	(a)  (b)  (c) 

Note: Description and visual depiction of boat categories used for the Mississippi Sound Wild Dolphin Project.

Table 2

Behavioral States

State	**Description**
Feed	Majority of group engages in foraging behaviors such as repeated fluke-in/out dives in one location, feeding circles/splashes, fish kicks/toss, etc.
Social	Majority of group in almost constant physical contact with one another, engaging in group social balls and often displaying surface behaviors.
Travel	Majority of group moving steadily in one direction (slow or fast).
Mill	Majority of the group is moving in various directions in one location, with no apparent physical contact between individuals.
With Boat	Majority of the group approaches or travels alongside a boat.
Rest	Majority of the group drifting at surface.
Other	Majority of the group is engaging in a state not listed.
Underwater	Majority of the group is not visible (i.e., underwater), but location is known.
Not Found	Majority of the group is not located at/during interval.

Note: Description of behavioral states used for the Mississippi Sound Wild Dolphin Project from July 2006 to August 2012.

Inclusion Criteria

In order to be included in analysis, dolphins must have been recorded as neutral upon research vessel approach. Neutral was operationally defined as pods that did not attempt to approach the research vessel, nor attempt to evade the research vessel. Since I was interested in dolphins' behavioral response to other boats in the area (and not the research vessel), it is imperative that the dolphins used for this study responded in a neutral manner to the research vessel. In this way, the behaviors reported can more reasonably be contributed to effects of the other boats in the area. Additionally, encounters had to have coded behavioral states for at least 15 minutes (the shortest encounter length duration), with the same amount of time available before a boat event (e.g., boat further than 100 m) and after a boat event (e.g., boat closer than 100 m). If these timespans differed, I used a conservative measure by choosing the shorter duration. Therefore, every encounter was coded for the same amount of time before and after each boat event. The distance requirement of 100 m was replicated following previous studies in the area (Miller at al., 2008). Additionally, only one boat was present for the entirety of the event duration, as it was not possible to differentiate effects from various boat types in one session, and stacked effects may result from increased quantity/density, skewing results (Bas et al., 2014). If dolphins were not neutral upon approach, session was not at least 15 minutes long, observation did not have some amount of time before a boat event (more than 100 m away) followed by some amount of after a boat event (less than 100 m away), or if more than one boat was present for the duration of the event, the data point was be excluded.

Analysis

MATLAB was utilized for preliminary sorting of events and inclusion criteria (Table 3). Microsoft Excel was used for data organization and figure creation, and SPSS statistical software was used for statistical data analysis.

Table 3

Cumulative Frequency of Each Boat Type

Boat Types	*f*	Cumulative *f*
Sailboat	>	1

Table 3 (continued).

1	Sailboat (unspecified size)	1	**1**
2	Small Sailboat (5ft-10ft)	0	^
3	Medium Sailboat (10ft-25ft)	0	^
4	Large Sailboat (>25ft)	0	^
	Recreational Boat	>	49
5	Recreational Boat (unspecified size)	2	^
6	Small Recreation (5ft-10ft)	20	^
7	Medium Recreation (10ft-25ft)	23	^
8	Large Recreation (>25ft)	4	^
	Fishing Boat	>	17
9	Fishing Boat (unspecified size)	7	^
10	Small Fishing (5ft-10ft)	6	^
11	Medium Fishing (10ft-25ft)	4	^
12	Large Fishing (>25ft)	0	^
13	Shrimp Boat	5	5
14	Tug/Barge/Shipping Boat	9	9
15	Ferry	5	5
17	Patrol Boat	7	7

Note: Frequency of encounter for each boat type (n=93). Highlighted boat types represent each main category of boat and their associated cumulative frequency.

MATLAB Sorting

I began with 2,431 events. These were composed of any boat event recorded from 2003 to 2012. My first lines of code eliminated any data collected prior to July 2006 (390 events). The next lines of code eliminated any event less than 15 minutes in duration (283 events). This was followed by code that eliminated any event with a boat greater than 100 m away (1,460 events). Finally, I wanted to ensure that only one boat was present in the event, so I eliminated any events with more than one boat present in the same timeframe.

A total of 93 encounters remained after data were selected (Table 3). However, only 1 sailboat event was left in the dataset (Table 3). Therefore, it was excluded from analysis and 92 encounters were analyzed.

Research Questions

(1) Was there a difference in dolphins' behavioral states before and after boat presence? (2) How did different boat types (i.e., recreational boats, fishing boats, shrimp boats, shipping boats, ferries, and patrol boats) affect dolphin behavior?

Mixed Multivariate Analysis of Covariance (MANCOVA)

This study utilized two predictors (time as IV_1 and boat type as IV_2), in which IV_1 was the within-subjects variable acting as the random effects factor subjecting dolphins to repeated measures (i.e., before and after a boat event), and IV_2 was the between-subjects variable acting as the fixed effects factor (i.e., recreational boat, fishing boat, shrimp boat, shipping boat, ferry, and patrol boat). Having the aspects of both a factorial MANCOVA (e.g., two or more IVs) and a repeated measures design, this statistical analysis classified as a mixed design (Field, 2013). The behavioral states accounted for 9 dependent variables (DVs) within the context of the before and after conditions (IV_1, two levels, repeated measures) and between the various boat types (IV_2, six levels). Covariates included (1) speed and (2) distance of passing boat, and all means below have been adjusted during SPSS computation as a result. Simple first standard contrasts were used in order to compare effects from one boat type to the other five boat types. The multivariate test statistic used (Roy's Largest Root) represents the amount of explained variance to unexplained variance (SS_M/SS_R) for the first discriminant function, and is the most appropriate and powerful test statistic when group differences focus on one variate (Field, 2013; Park, Cho, & Ki, 2009).

CHAPTER III - RESULTS

Research Question 1

When time was the only independent variable of interest, all boat type categories were collapsed. A subtle pattern emerged indicating that dolphins would feed, travel, and swim underwater less often after a boat event (Figure 3). Simultaneously, dolphins seemed to increase their "not found" behavior, or disappear, more often as a result (Figure 3). The literature supports labeling this type of behavioral response avoidant or evasive, and it is expected in this situation (see introduction for an review of the literature). The dolphins also appeared to mill more after boat events, which is discussed less in the literature and elaborated on here (see discussion). However, while all boat types were collapsed, the multivariate omnibus test determined that none of the differences described above were significant, $\Theta = 0.08$, $F(8, 77) = 0.80$, $p = .61$. In addition, the covariates for boat speed and distance did not have a significant effect on dolphin behavior on their own ($\Theta = 0.03$, $F(9, 76) = 0.29$, $p = .98$; $\Theta = 0.10$, $F(9, 76) = 0.80$, $p = .61$), or in conjunction with time ($\Theta = 0.10$, $F(8, 77) = 0.96$, $p = .47$; $\Theta = 0.12$, $F(8, 77) = 1.15$, $p = .34$).

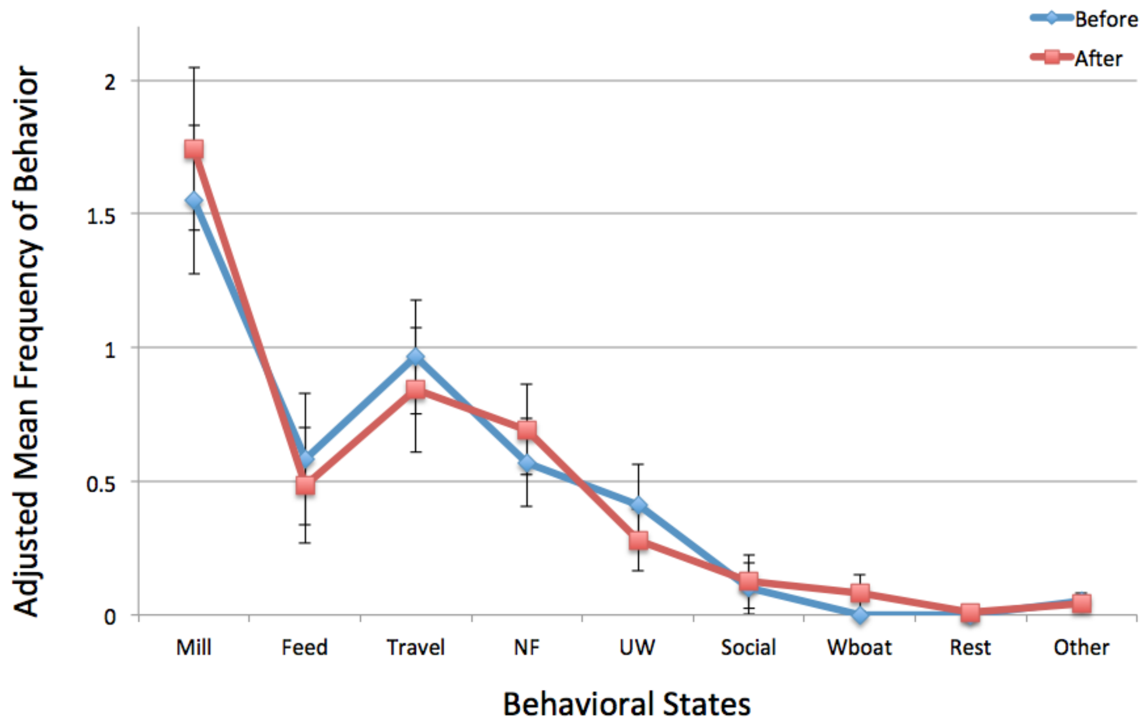

Figure 3. Main Effect of Time.

Average behavioral state frequencies for a group of dolphins before and after a boat passes in the Mississippi Sound.

Research Question 2

There was however, a significant interaction between time (e.g., before and after a boat event) and boat type, Θ = 0.25, $F(8, 81) = 32.53$, $p = .02$ (Figure 4 and 7). Upon examination of the univariate tests, only one behavioral state achieved statistical significance: other ($F(5, 84) = 2.55$, $p = .034$, $\eta_p^2 = .132$). Figure 4 and 5 were created to assist describing these interactions. The adjusted mean frequency of a behavioral state before a boat event was subtracted from the adjusted mean frequency of a behavioral state after a boat event to calculate the difference scores for these figures. Therefore, a negative difference score indicates that a behavioral state decreased in response to boats, whereas a positive difference score depicts the extent to which a behavioral state increased (Figure 4 and 5).

The behavioral state coded as "other" decreased after a patrol boat approached, but increased after ferry or fishing boat events (Figure 4). It is important to note that other was operationally defined simply as a behavioral state not otherwise listed in the ethogram (Table 2). Therefore this state may have included a wide range of behaviors, of which had the possibility to differ functionally in each boat type context.

Although the remaining eight behavioral states were not statistically different between boat types, it should be mentioned that these behavioral states had very low levels of observed power, and hence an increased probability of type II error. The patterns present in this data may still help describe how different boat types affect bottlenose dolphin behavior. For example, there appeared to be an overall trend for dolphins to increase not found (NF) behavior after most boat type events (Figure 4 and 5). They were especially elusive during shipping, ferry, and fishing boat events (Figure 4). Interestingly, dolphins only reduced NF behavior around shrimp boats and chose instead to mill around them in plain sight. Likewise, dolphins increased mill behavior after patrol boat, shipping vessel, and fishing boat events, but milled less around ferries (Figure 4). Dolphins fed less after patrol and recreational boats events, yet fed more after fishing, shipping, shrimp, and ferry boat events. Dolphins were more social following fishing and patrol boat events, and only marginally more social after recreational and shrimp boat events. There was no difference in social behavior during shipping vessel events, but dolphins decreased social behavior after ferry boat events. Rest was only marginally affected across all boat types, but dolphins appeared to rest most after fishing boat events and loose rest after ferry and recreational boat events.

Dolphins had the same reaction across most, if not all, boat types in three of the nine behavioral states (Figure 4). Almost every boat type caused dolphins to cease traveling; the exception was recreational boats, which caused dolphins to travel more (Figure 4). Dolphins were also likely to perform fewer behaviors underwater following most boat type events. It is logical that dolphins would spend more time "with boats" after they are within radius of the pod. However, dolphins only spent a notable amount of time with ferry, fishing, and recreational boats, in that order.

Anecdotally, a different pattern was found for the sailboat event (Figure 6). Although care should be taken to avoid over-interpretation of results from a single event (n = 1), dolphins were especially evasive in response to the sailboat; they exchanged milling and underwater behaviors for not found (Figure 6).

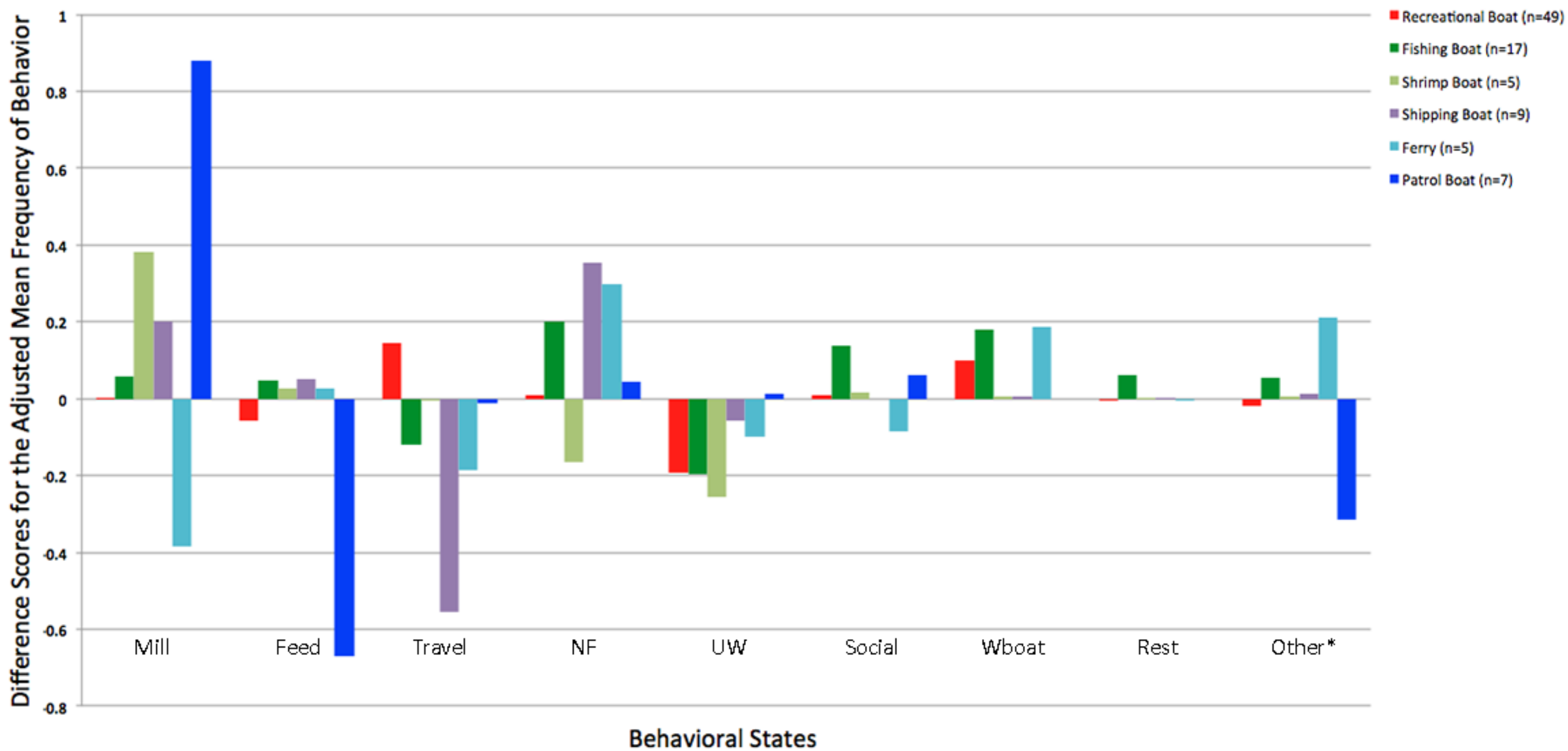

Figure 4. Main Effect of Time and Type Organized by Behavioral State.

Difference scores between the average behavioral state frequencies for a group of dolphins before and after a boat event in the Mississippi Sound. Each color represents one of seven different boat types. *Indicates a significant difference.

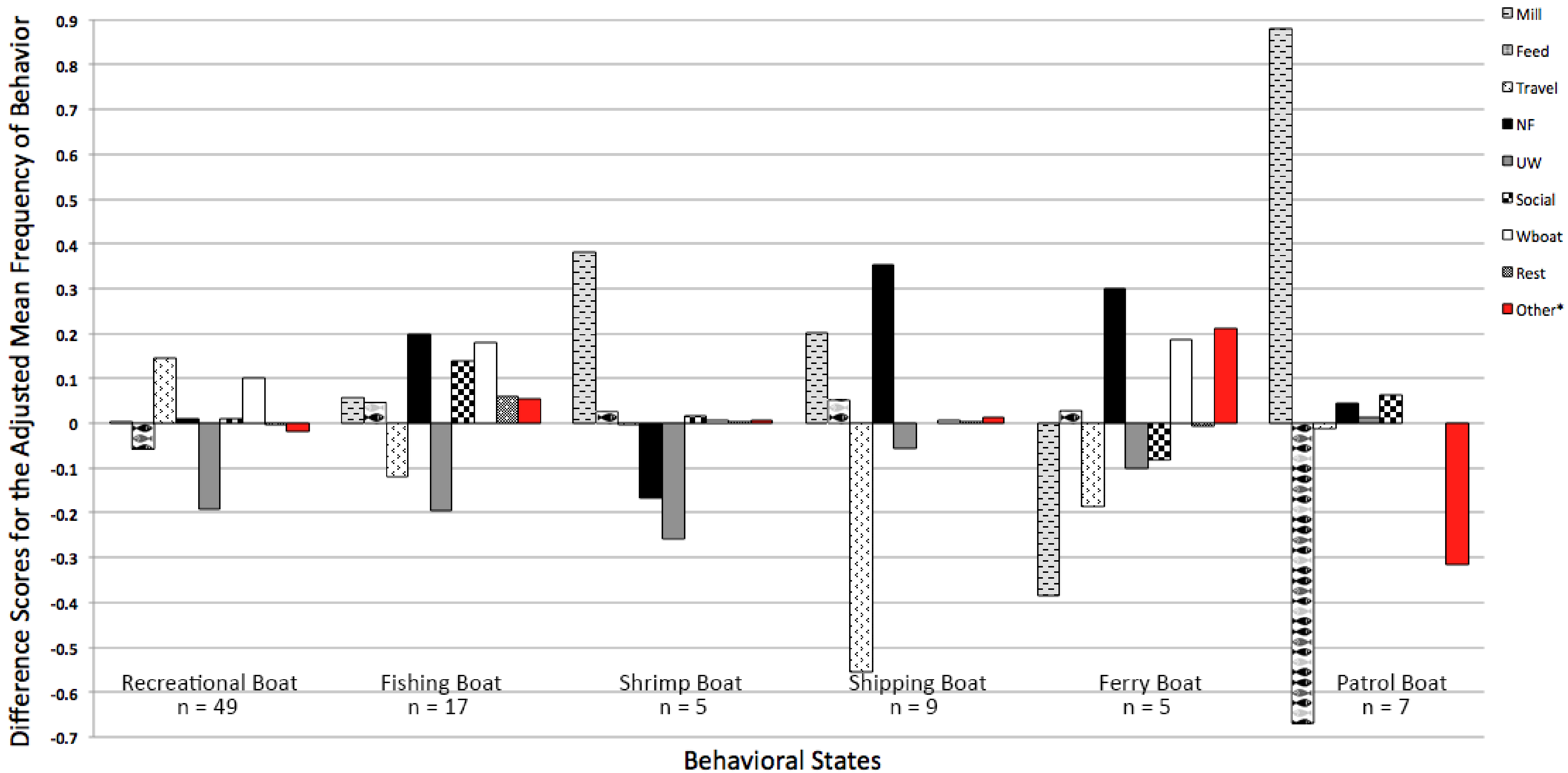

Figure 5. Main Effect of Time and Type Organized by Boat Type.

Difference scores between the average behavioral state frequencies for a group of dolphins before and after a boat passes in the Mississippi Sound. Six different boat types are shown on the x-axis with their associated sample size. *Significant behavioral states are shown in red bars above.

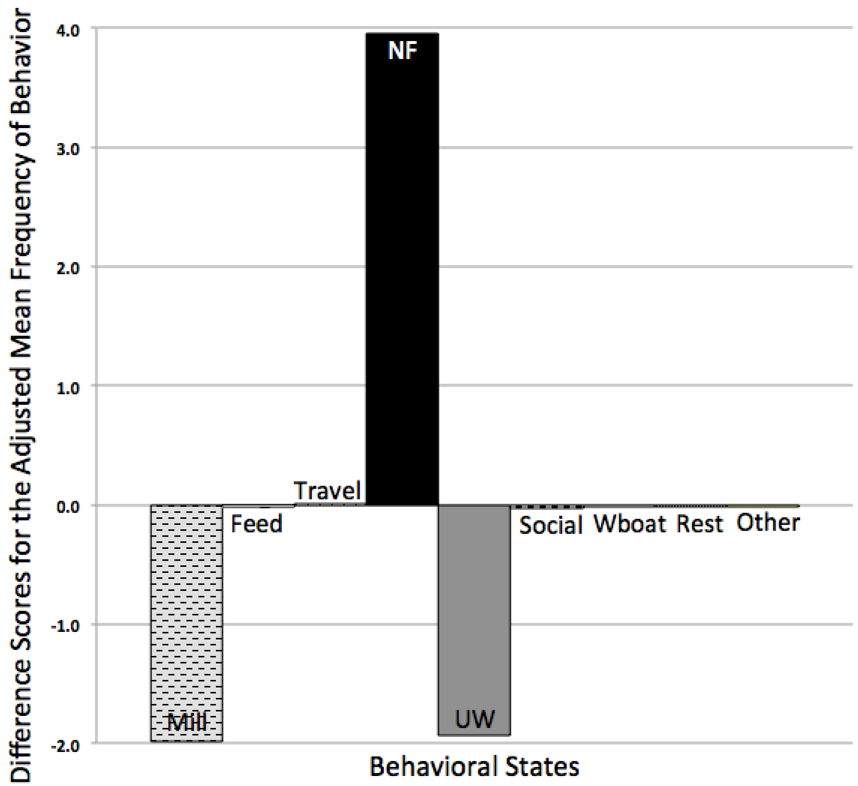

Figure 6. Anecdotal Sailboat Example.

Difference scores between the behavioral state frequencies for a group of dolphins before and after a sailboat (n=1) passes in the Mississippi Sound.

CHAPTER IV – DISCUSSION

Research Questions

Much of the literature on boat traffic and anthropogenic effects on dolphin behavior either focuses on only one boat type, collapses between boat types, or ignores them altogether. When boat types from the Mississippi Sound were collapsed, the difference between dolphins' behavioral states before and after boat events were not statistically significant. If this study simply ended on the discussion of general boat traffic and did not explore further into the effects of various boat types, it would appear as if the dolphins were undisturbed by any boat presence. However, when boat types were separated out in the analysis, behavioral changes before and after boat events became significant. In this way, this study provides evidence that dolphins are indeed affected by boat presence, and further that different types of boats effect dolphins in different ways.

Behavioral Response Strategies by Boat Type

Recreational Boats: a Quick Departure

Classified by their use of an engine, recreational boats are notorious throughout the boat traffic literature for their high speeds, often compact size, and erratic paths. There are also many recreational boats sharing the same warm coastal waters as dolphins, making this type of boat too numerous to avoid for long (Buckstaff, 2004). For a large part, dolphins in the Mississippi Sound maintained a horizontal "flee" response to recreational boats. Out of all boat types, travel increased the most for recreational boats (Figure 5). This should not be surprising based on previous literature which examined only recreational boats (Miller at al., 2008). However, this strategy was unique compared to other flee strategies discussed below. In response to recreational boats, dolphins chose the quickest path to escape: the surface (evident by their decreased time underwater). In addition, dolphins stopped foraging, resting, and “other” behaviors in order to swim with intent. Due to the erratic paths and large wakes characteristic of high-speed boats, dolphins also increased their behaviors with the boat, choosing to swim in the speedboats’ wake. The dolphins’ intent cannot be known in this study, but it can be inferred that either the dolphins are in this instance being enriched by the speedboats’ wakes enough to outweigh the opportunity to forage/rest, that the speedboats have already ruined their opportunity to forage/rest and they are merely chasing the subsequent path of the fish or opportunistically using the enrichment, or that the group is collectively choosing the path of least physical resistance and harm upon their escape. After all, if one were to escape an erratic predator, the options are to energetically change path directions or stay by the predator’s side.

Fishing Boats: Trade-Off

Operationally defined by the necessity to have fishing lines in the water (Table 1), there should be a predisposition for fish to be in the general vicinity (or onboard) of a fishing boat. Dolphins in the Mississippi Sound foraged more and congregated nearby fishing boats. They also milled, socialized, rested, and conducted “other” behaviors visibly (e.g., above water) in the presence of fishing boats. The rise of NF behavior in this context was not necessarily indicative of evasive action, as dolphins may have merely foraged deep under the water or out of sight. The distinct decrease in travel behavior also supports the claim that dolphins’ desire to eat and socialize outweighed the disturbance of the fishing boats’ presence.

Shrimp Boats: Trade-Off and Wait

Like fishing boats, there is a predisposition for prey to be in the general vicinity (or onboard) of a shrimp boat. However, shrimp boats differed from fishing boats as they were exclusively large (e.g., more than 25 feet long; Table 1). Additionally, while fishing boats were required to have lines in the water (and by relation indicate that fish were in the area), shrimp boats were still operationally defined as shrimp boats even if they are not actively trawling and their nets are up. A different pattern may have been seen if different boat contexts (nets up or down) had been separated. Dolphins still foraged more, socialized, rested, and congregated nearby shrimp boats in the Mississippi Sound, just comparatively less than fishing boats. Additionally, while NF behavior increased during fishing events, NF behavior decreased by nearly just as much during shrimp boat events. In fact, the overall trend for shrimp boats seems to be the increase in visible behaviors, such as milling (Figure 5). The fact that both NF and underwater behavior substantially decreased in response to shrimp boats supports one of three hypotheses: (1) dolphins' desire to visibly mill and eat still outweighed the disturbance of the shrimp boats' presence, (2) dolphins' are waiting on the surface for the boat to pass in order to conserve energy, or (3) both strategies are at play. It is conceivable that dolphins under different contexts would be flexible, and implement the most appropriate behavioral response for a given situation. For example, while nets are cast, dolphins may actively forage like they would during a fishing boat event. However, when nets are up and full of shrimp, it would be most opportunistic to mill at the surface and wait for food to drop. Additionally, if nets are up and no prey is detected, the risk of the large trawler outweighs the benefit, and a similar strategy to ships is implemented: they wait. While these contexts were not separated in this analysis of shrimp boats, we see an overarching pattern that is similar to the fishing boat's trade-off strategy, mixed with a waiting strategy of unknown intention.

Tugs, Barges, and Shipping Boats: Do I Stay or Do I Go

Characteristically large and loud, shipping vessels and all associated boat types (e.g., tugs and barges) incited a very different behavioral response compared to dolphins' recreational boat "horizontal flee" strategy. Even when dolphins were traveling prior to shipping boat events, they halted in response. The increase in mill behavior, noticeable decrease in travel, and the subtle increase in other visible behaviors such as with boat and rest, indicates that dolphins may have been at least partially using the "wait" strategy described below. However, the slight increase in foraging behavior may indicate a trade-off scenario. Further, the increase in NF behavior is the most substantial behavioral response when compared to all other behavioral differences within this boat type, and may either (1) support the notion of the trade-off strategy (e.g., with deep water foraging as seen in fishing boat contexts), or (2) indicate attempts to "vertically flee" or dive into deep water in order to avoid the large current and loud sounds being propagated by shipping vessels in the Mississippi Sound.

Ferry Boats: Fun or Flee Departure

Large, consistent, and traveling on a set course, ferry boats like the Ship Island Ferry offer daily round-trip transportation services from Gulfport to Ship Island, as well as private charter trips. This one company crosses the Mississippi Sound 2-8 times a day (Ship Island Excursions, 2017). Regardless of their destination, ferries generally have short-range destinations, predictable paths, and non-erratic behavior. Combine this predictability with a hull large enough to create a substantial wake, and it is evident why dolphins would choose to visibly swim “with boat” in response (Figure 5). However, is the enrichment of the wake (in combination with increased feeding opportunity) a large enough trade-off for dolphins to halt travel, mill, rest, and socialization behaviors? Alternatively, these dolphins could be opportunistically using the wake of the ferry boat to travel with less effort. The increase in NF behavior in this boat context could be indicative of the dolphins (1) diving in the wake of the ferry boat and foraging out of sight, or (2) avoiding the ferry by diving deeply out of the wake and away from the boat event altogether.

Patrol Boats: Wait

Boats operated by the U. S. Coast Guard could be any size, yet those coded in this dataset are consistent in that they were all likely to approach the research vessel quickly during an encounter. As a result, dolphins who were previously foraging in the Mississippi Sound may have been surprised, but were more likely overstimulated or simply aware that if they stayed put, the approaching vessel would depart soon after. In this situation, dolphins halted all feeding behavior, any trace of travel or “other” behaviors, and instead milled substantially more. They also spent marginally more time underwater, out of sight, and socializing (Figure 5), but for the most part appeared to wait for patrol boats to pass.

Sailboats: (tentative) Flee

Although there was only one example (n=1), the reaction to the sailboat event was unexpectedly evasive. Required by operational definition to have any motor powered off, and a “sail currently up” (Table 1), sailboats are typically thought of as the least hazardous boat type, and are rarely even discussed in boat traffic literature. However, this single sailboat event inspired the most substantial avoidant behaviors among all other boat types in this dataset. This is mainly supported by the dolphins' significantly evasive (NF) behavior, and the reduction of their above (e.g., milling) and below water (e.g., underwater) behaviors, in response to the sailboat event. It is important to clarify that only one sailboat event was present in the data. Therefore, it is possible that this group of dolphins may have been particularly sensitive due to group composition (e.g., many young or pregnant dolphins), and responded evasively due to the sailboat's behavior (e.g., erratically moving path) or the type of passengers (e.g., boisterous and invasive) that approached.

To Mill or Not to Mill: Differential Behavioral Response Strategies

The behavioral state "mill" depicts an interesting story in the data. On the surface, it seems to oppose the logic that dolphins evade most boats by fleeing, or rather, increasing their travel, underwater, and not found behavioral states. That expected pattern is present in the NF data: dolphins disappeared (e.g., took longer and deeper dives, or swam away altogether) after all boat events except shrimp boats. So, despite that, why did dolphins mill?

Flee

Dolphins responded to the sailboat event primarily by evasion (Figure 6): they fled (increase NF and travel), not bothering to wait on the surface (e.g., mill) or otherwise (e.g., underwater). Likewise, they were not engaged in productive behaviors (e.g., reduction in feeding and social behaviors; Figure 6). The response to ferries was similar: NF increased and mill was reduced.

Trade-off

Excluding sailboats and ferries, dolphins increased milling in response to every other boat type (Figure 5). However, there may be a different purpose for milling during different boat type events. In some boat type contexts, milling may be a matter of trade-offs. For example, if dolphins were feeding during a boat (e.g., fishing, shrimp, and shipping) event then the group may choose to mill, socialize, and rest rather than travel, flee, or spend time underwater. Likewise, when dolphins milled following patrol boat events, socialization increased. In either context, it is possible that the access to food and/or companionship (sexual and otherwise) outweighed the cost of the actual boat disturbance. The opportunity for foraging is especially relevant when considering the function of shrimp and fishing boats.

Wait

However, there may be another reason that dolphins in the Mississippi Sound would choose to mill instead of travel in response to ships, or mill instead of most behaviors in response to patrol boats (Figure 5). Even though dolphins increased socialization in response to patrol boats, they also stopped feeding (Figure 5). They traveled less, were underwater more, and disappeared more as well. This strategy appears different from the last two (i.e., “flee” and “trade-off”) described, and suggests that dolphins may have been choosing instead to “wait it out.”

Perhaps mechanistically similar, deer have evolved sensitive retinas adapted for nighttime navigation that causes them to freeze (instead of flee) when confronted with the bright headlights of approaching vehicles (Blackwell & Seamans, 2009). Whereas deer rely primarily on vision, dolphins’ primary sensory modality involves their acoustic system (Au et al., 2015). Living underwater, dolphins evolved acute perceptions of sound and are able to detect even slight differences in tonal signals (Branstetter, Black, & Bakhtiari, 2013; Janik, Sayigh, & Wells, 2006) and pulsed echoes (Li, Nachtigall, & Breese, 2011). Similar to the physiological limitation of deer's behavioral response, it is possible that dolphins in the Mississippi Sound could be overstimulated by a specific attribute of boat traffic, such as a feature of the noise produced. Alternatively (or perhaps additionally), dolphins will sometimes choose to remain silent in response to loud noise rather than incur the extra metabolic cost of increasing their repetition rate, frequency, amplitude, or duration of their vocalizations (Holt et al., 2015). Likewise, dolphins may also choose to quiet their behavior during very disturbing contexts. This strategy would benefit the pod in multiple ways: by remaining close together, the milling group would limit the risk of stray individuals, especially calves. Additionally by remaining stationary, the group would not have to predict the path of the traveling (and potentially erratic) patrol boat, thereby avoiding the path and limiting the risk of physical harm from vessel propeller engines. Using this behavioral response strategy, dolphins "avoid" vessels without expending the energy required for deep dives, quick travel, or utilizing the Lombard effect to either navigate through the environment or communicate effectively to the group (Buckstaff, 2004; Holt et al., 2015; Veirs, Veirs, & Wood, 2016).

Hybrid

Even among one boat type, multiple strategies could be combined as dolphins in the Mississippi Sound reacted to a complex combination of different boat features such as size, distance, wake, and sound propagation. In addition, the behaviors of the boat, such as speed and predictability of path, may have changed drastically depending on the boat's function (and in some cases, the captain's steering).

In conclusion, this data suggest that there was more than one-way dolphins were responding to boats and that to some extent their response was dependent on boat type. Therefore, this report provides evidence for distinguishing boat types during boat traffic studies.

Future Directions

Future boat traffic surveys should be cautious when designing their research study. If there is more than one type of boat in the study area, researchers should gather data on all available boat types. Furthermore, studies must include boat type when interpreting anthropogenic effects on animal behavior. By accounting for multiple boat types in one area, we can better understand how different boat behaviors (e.g., speed, driving pattern) and features (e.g., size, shape, engine type, acoustic features of noise production and propagation) affect marine mammals.

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