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INFLUENCE OF TIDAL CYCLES ON MOVEMENTS OF ATLANTIC BOTTLENOSE DOLHPINS (*TURSIOPS TRUNCATUS*) IN SOUTH CAROLINA COASTAL ENVIRONMENTS
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BY

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Abstract

When studying estuarine environments that are directly fed by the ocean tides, the impact of the changing tide is vital in studying the migration and travel behaviors of organisms within those environments. This study was aimed at determining the influence of the daily tidal currents on movement with or against the tides by Atlantic bottlenose dolphins (*Tursiops truncatus*). Data collection occurred from March to October 2012, at three study sites: the ACE River Basin National Wildlife Refuge, the Hilton Head estuary, and the Cape Romain National Wildlife Refuge. Photo identification transect surveys were conducted to observe resident Atlantic bottlenose dolphins (*Tursiops truncatus*) in coastal South Carolina estuarine systems. Travel direction was analyzed using Chi square tests for significance with respect to the overall data set, study site, presence of calves in the group, size of the group and tidal stage. Travel direction was found to be significant ($p < 0.05$) within events where travelling was observed, with most movement occurring against the tide. For data where travelling was observed, travel direction was also found to be significantly against the tide ($p < 0.05$) for two of the six tidal stages; tidal stages were defined as high ebb, mid ebb, low ebb, low flood, mid flood, and high flood. No significant results were found in accordance with the other factors. Studies have shown that many dolphin prey species move concurrent to the tidal changes, and so the dolphins may have a strategy of feeding while swimming against the current.

Introduction

Estuarine environments are among the most abundant coastal environments found in South Carolina. Partially-mixed estuaries, such as most estuaries found in the state, are equally

influenced by both the freshwater river influx as well as the oceanic seawater intrusions. The behaviors of the organisms found in such environments are thus impacted by various abiotic and biotic environmental factors that accompany these mixing water masses. Tidal cycling is one such important consideration when studying the behaviors of species in estuaries.

Daily movements and distributions of estuarine bottlenose dolphins have been studied in consideration with diel tidal changes, with varying results. In a long-term study on general behaviors of the population near Sarasota Bay, Florida, more dolphins were observed moving with the tide, although no statistical analysis was completed due to the large number of “milling” observations (Irvine *et al.*, 1981). Scott *et al.* (1990) referenced fishermen that claimed the dolphins entered the shallow sea grass with the flooding tide, and entered the deeper waters with the ebbing tide. In the Sado Estuary, Portugal, Harzen (2002) found that movements and speed could be predicted accurately with tracking equipment, and that the dolphins generally moved with the tide. Mendes *et al.* (2002) studied the distribution of the species in the narrow Kessock Channel, Moray Firth, Scotland in relation to tidal movements and the formation of a tidal front; significantly more dolphins were observed in the channel during the flood tide than the ebb tide. There are also studies that give the opposite result, showing significant movements against the tides. Near Sarasota Bay, Irvine *et al.* (1981) found that larger groups of animals moved with the tide; however, in channels with the strongest current (exceeding 5 km/hr), the dolphins moved frequently against the tide. Shane (1980) observed dolphins moving against both the ebb tide and flood tide (mostly the ebb tide) in the lower half of the study area, near the Gulf of Mexico. When studying the franciscana dolphin

(*Pontoporia blainvillei*), Bordino (2001) found that the data indicated that the relationship between the dolphins' diurnal swimming movements and the tidal stage was significant; dolphins were seen to move against the tide during ebb and flood tides. Other studies have also shown no significant movement with or against the tides (Bailey and Thompson, 2006).

Theories behind movements with the tide have been suggested, and many studies found that tidal movements could be used as possible foraging strategies. Scott *et al.* (1990) noted that the dolphin prey species (mullet) were known to follow the flooding and ebbing tide, the pattern that was also observed in those dolphins. Harzen (2002) suggested that the need to forage might be the strongest indicator of tidal movements, aggregation behaviors, and general predictability of the data presented by the tracking equipment. Sargeant *et al.* (2005) found that beach hunting correlated with tidal state and habitat use. Beach hunters used shallow water and incoming tidal stages to hunt, which also influenced the degree of social interaction with the non-beaching individuals. Other studies have suggested energy efficiency as an influence on behaviors in marine mammals. Williams (2001) completed a study on the locomotion of bottlenose dolphins, *Tursiops truncatus*, northern elephant seals, *Mirounga angustirostris*, and Weddell seals, *Leptonychotes weddellii*, particularly the respective effects of travelling and diving on cost of transport (COT); it was found that marine mammals have behaviors to mitigate the costs of travelling, including porpoising, wave-riding, and gliding when descending for dives.

The purpose of this study was to gather data on the influence of tidal changes on resident bottlenose dolphin movement at three locations along the South Carolina coast. The

study was conducted in the ACE Basin National Estuarine Research Reserve, Hilton Head, SC, and the Cape Romain National Wildlife Refuge. The following null hypotheses were examined: (1) daily movements of bottlenose dolphins are not significantly influenced by the tide (2) dolphins do not significantly alter their movements based on tidal stage, (3) there is no significant difference in tidal movements of dolphins between each of the 3 study areas, (4) the presence of calves in the group does not significantly alter the group movements with respect to tide.

Study Area

The study was completed in three estuarine locations along the South Carolina coast: the ACE Basin National Estuarine Research Reserve near Beaufort, SC, Hilton Head, SC, and the Cape Romain National Wildlife Refuge near Awendaw, SC. The ACE Basin National Wildlife Refuge is a convergence of the Ashepoo, Combahee and Edisto Rivers, and is represented by an array of natural habitats. It is approximately 4781 ha, including 1598 ha of tidal marsh and 1214 ha of managed wetlands (McGregor *et al.*, 2009), all of which drain into the Atlantic Ocean via the St. Helena Sound. The Edisto River is tidally influenced within 21.7 km of the coast and the saltwater interface extends approximately 12.4 km inland during high tide; the freshwater-saltwater interface for the Combahee and the Ashepoo rivers are located about 24.8 km inland and 18.6 km inland, respectively (Hydrology, www.dnr.sc.gov). Data collection for this study was focused primarily in the Bull River and its side creeks.

The Hilton Head site was focused in Bull Creek and sections of the May River near Bluffton, SC. The tidal creek is part of the Calibogue Sound salt marsh estuary, and is composed of several large side creeks (Fox, 2010).

The Cape Romain National Wildlife Refuge extends 35.4 km along the coast, and covers 12545.3 ha of open water as well as 14280.1 ha of beach and sand dunes, salt marsh, maritime forests, tidal creeks, fresh and brackish water impoundments (Cape Romain National Wildlife Refuge, www.fws.gov) The CRNWR is the largest of five barrier island/salt marsh wildlife refuges on the eastern United States coast (Gough *et al.*, 1994). This study was focused in the southern Bull River and Pompano and Five Fathom Creeks.

Methods

Data Collection

The data for this thesis were collected in conjunction with research conducted by Jessica Conway, a graduate student of Coastal Carolina University. Data collection occurred from March 10, 2012 until October 10, 2012. At each site, boat-based photo identification surveys were conducted along pre-determined transects. Each boating day, information was recorded that included starting and ending times, number and times of transects completed, high and low tide, photoperiod, and the number of events that occurred per transect as well as in total. An event was defined as the sighting of one or more individuals. Once an event occurred, the dolphins were followed until an identifiable photograph of each individual was taken. Data parameters for each event were taken as the event occurred, including GPS starting and ending location, general river or descriptive location, estimates on number of individuals, water and air

temperatures, weather and creek states, behavior, direction of movement with respect to the tide, and number of calves present in the group. Collection of behavior and travel direction did not begin until April 14, 2012. Approximately 231 hours total were spent in the field, with approximately 215 of them including behavioral and travel direction data. Of the 215 hours including the relevant data for this thesis, 89 hours were spent actively following and photographing dolphins, being described as “on effort”.

Data Analyses

In order to determine whether significant directional movements were observed, the data set was narrowed to events during which behaviors of a “travelling” or “milling” state were recorded. Behavioral states included travelling, milling, feeding, and social. If an event listed multiple behaviors (i.e. travelling and fluking), the dominant state of behavior was assigned. In this example, the act of fluking is merely a behavior that occurred while the group was travelling; therefore the event was designated as travelling. For all events designated as travelling, direction of movement was defined as being either “with” or “against” the tide, based upon the tidal stage. Tidal stages were defined as high ebb, mid ebb, low ebb, low flood, mid flood, and high flood, based upon pre-determined high and low tides. The time between tidal peaks was proportioned between three stages, and in the field those times were general guidelines when determining the low, mid, or high status of the stage. Directional movement was analyzed separately as a function of each: the study site, tidal stage, presence of calves, and group size. A calf was defined as an individual of approximately 3 ft or less in length. Chi-square statistical tests for significance were used to determine if significant behaviors were

observed in each category, and Cramer's V and phi values were found to test the strength of all significant values.

Results

A total of 397 events were recorded during the observational time period, with 364 events including behavioral data. As shown in Table 1, the behaviors that were observed in the highest percentage were travelling behaviors. Behaviors that were categorized as either travelling or milling comprised approximately 86.5% of the total observed behaviors. It should be noted that there were a total of 370 events that occurred after the initial date of recording behaviors; six events did not have recorded behaviors due to equipment failures and weather conditions.

In order to study the travel direction, only behaviors classified as travelling were considered and all directional movements were taken from those events; 187 events were thus analyzed (Table 2). From the original 212 travelling events, there were 25 for which the direction of movement was either not recorded, defined as milling, or took place during slack tide and were therefore indeterminable. When observing directional movements, there were 27 more events during which groups were observed going against the tide than events going with the tide. When using the Chi square test of significance against expected results, the travel direction was found to be significant at $p=0.04833$ ($\alpha = 0.05$) (Table 2 and Figure 2). The site with the highest number of travelling behaviors recorded was in Hilton Head, followed by Cape Romain and ACE River Basin (Table 3). Cape Romain had the highest percentage of "against"

events at 60.3% of total Cape Romain events. All locations had more events of dolphins moving against the tide, although no site was significant (all p -values >0.05).

Two of the tidal stages were found to have significant directional movement. Using the Chi Square significance test, mid-ebb tide and high flood tide were both found to have significant movement against the tide (Figure 4). Two of the tidal stages, high ebbing tide and low flooding tide, had more movement with the tide; neither of these results were significant ($p>0.05$) (Figure 4).

For group dynamics, there were no significant differences between directional movement for groups with or without calves (Figure 5). Nor were there any significant differences in swimming direction relative to group size (Figure 6). The average group size was approximately 3.3 members.

The water and atmosphere parameters were found to have the following averages over the course of the data collection: water temperature average of 25.71°C, air temperature average of 29.76°C, and water salinity average of 30.96 ppt.

Table 1- Behavioral states for all observed events

Behavioral States	Number of Events	Proportion of Total Events
Travelling	212	0.58241758
Milling	103	0.28296703
Feeding	40	0.10989011
Social	9	0.02472527
Total	364	1

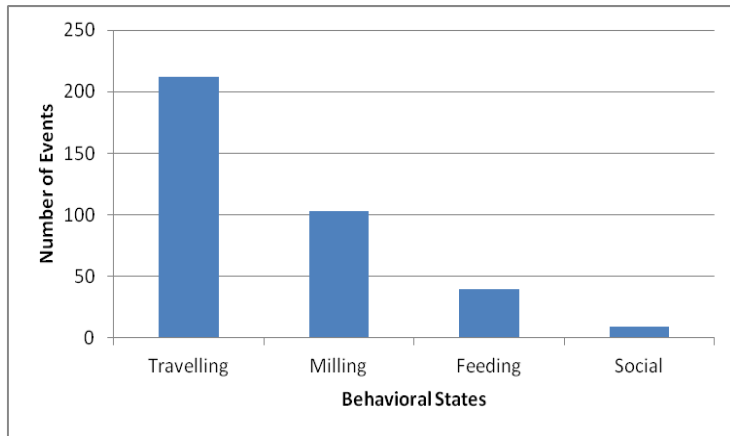


Figure 1 - Frequency of behavioral state as observed by the event

Table 2 - Direction of movement "with" or "against" the direction of the tidal water movement ($p=0.04833$, $\phi=0.144385$).

Travel Direction	Number of Events	Proportion of Events
With	80	0.427807
Against	107	0.572193
Total	187	1

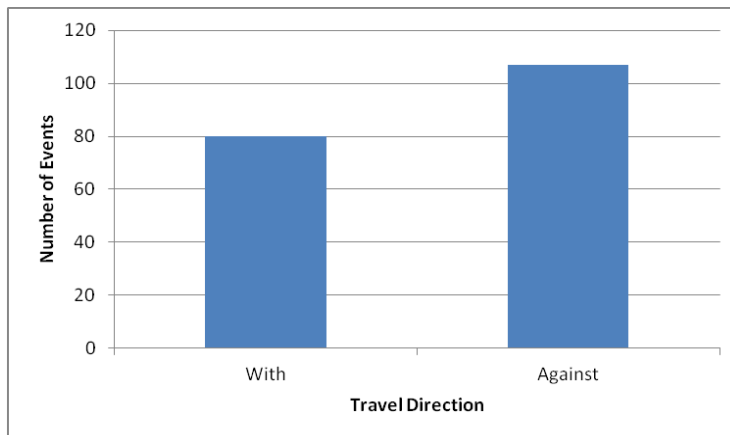


Figure 2- Comparison of number of events with versus against the tide ($p=0.04833$, $\phi=0.144385$).

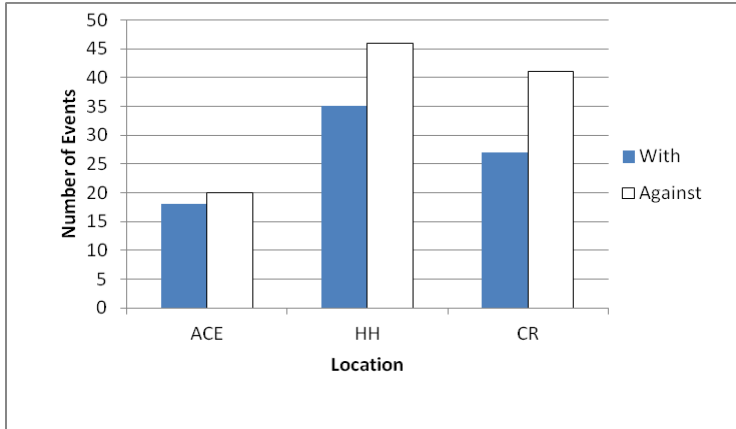


Figure 3 - Directional movement with respect to study site.

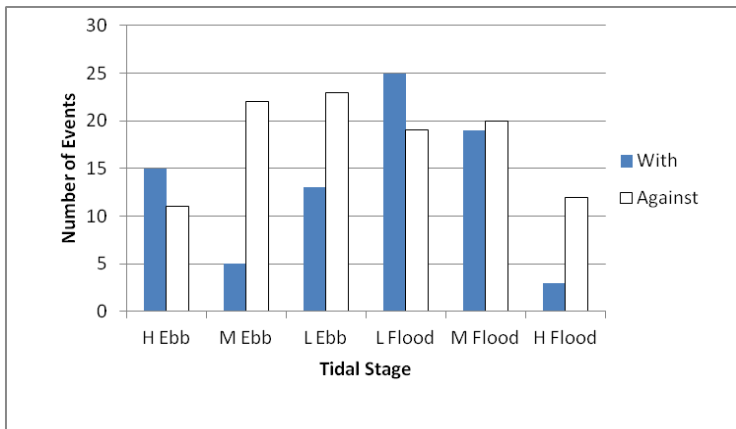


Figure 4 - Directional movement with respect to tidal stage ($p=0.001069$, $\phi=0.630$ for M Ebb; $p=0.020137$, $\phi=0.6$ for H Ebb). *Sample size was small for H Ebb, so significance may be invalid.

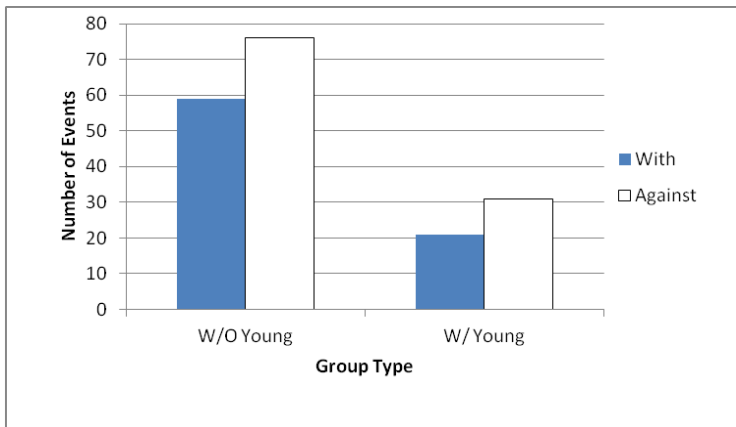


Figure 5 - Directional movement with respect to calf presence.

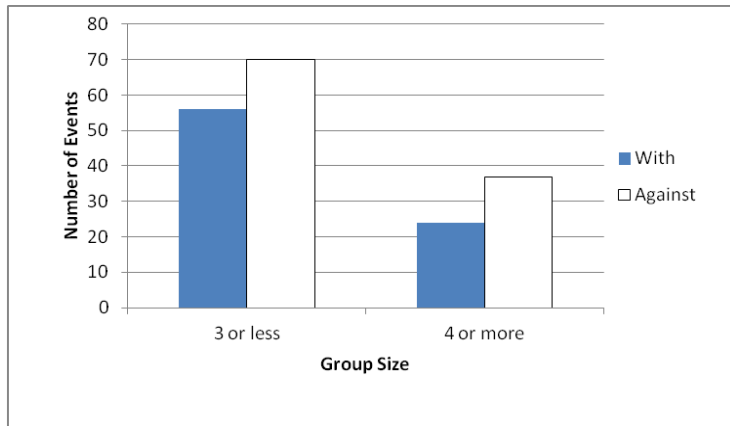


Figure 6 - Directional movement with respect to relative size.

Discussion

Gibson (2003) reviewed the tidal migration patterns in marine animals from multiple taxa and habitats; tidal migration, both horizontal and vertical, could play a variety of roles in different taxa. Migration was particularly common in the intertidal zone, which the author mentions can be a rich source of food. In most comparisons from this study, more dolphins elected to swim against the tide rather than with it. The significance of such movements, particularly those during the medium ebb and high flood stages of the tide, could be explained by a feeding strategy developed by the animals. By positioning themselves against the flow of water, the dolphins may be creating better opportunities to feed upon prey that travel with the tide.

Prey species of bottlenose dolphins have been studied more in depth with respect to behaviors. Barros and Wells (1998) presented data on the stomach contents and observed feeding behaviors of the Sarasota dolphin population. The data showed that the most common prey fish was the pinfish (*Lagodon rhomboides*), which contributed an explanation for the observations of feeding occurring over sea grass habitats. Such habitats are often made

inaccessible during stages of low tide, and the fish must compensate by leaving the area during the ebb tide. McCabe *et al* (2010) also compared the stomach contents to purse seine survey data; the most common prey fish was found to be pinfish. Pinfish are most likely a prey species of the dolphins in this study, which also suggests a possible feeding strategy based on the tidal movements of the fish. McDonough *et al* (2003) determined fecundity of striped mullet in the study area based upon the age and size of the organisms. A model for predicting the site fecundity of the fish when they are captured in the estuary was created. The reproductively developing fish were found most often between the months of October and February. This aligns with the seasonality of this study, indicating the prey supply might be more bountiful in the marsh.

Bretsch and Allen (2006) presented data on the presence of multiple taxa on the preferred depth shown by resident species in a salt marsh (*Palaemonetes* spp. and *Fundulus heteroclitus*). Species would migrate to the depth at which there was the least risk of predation and the least competition for resources. Previous field studies had shown that resident species entered the marsh earlier with the flood tide, so the preferred depth of the transient fish was not reached until higher tide. Sakabe and Lyle (2010) examined the spatial and temporal movements with respect to tidal fluxes and freshwater inflow into the study area on the east coast of Tasmania, with the data adding to the knowledge of species' handling of variable water environments. The authors found that the fish tended to move both in and out with the flooding or ebbing tide. Benefits of travelling with the tide included the access to previously-blocked foraging grounds by swimming with the flooding tide. The dolphins, adapting to take

advantage of these created feeding opportunities, could have been observed swimming against the tide in order to maximize their prey intake of such species.

No significant directional movement was found in relation to any specific study site. Most likely this is due to the similarities of the study sites. No significant directional movement was found in relation to group dynamics, either the presence of a calf or the overall size of the group. The lack of significance could be the result of the small sample size in each category; more data collection with group dynamics, including both group size and composition, could give rise to significant movement with or against the tides.

This study found that dolphin movement is significantly influenced by the tidal fluctuations that are found in salt marsh estuary systems. There was significant movement against the tides, which may be explained by the act of using a feeding strategy. However, this study bears further investigation to completely support this theory. Much previous research has shown that dolphins tend to move with the tide, which gives rise to the need for continued research in this study area. Differences between this study site and those of previous research could be the source of the opposite findings. Irvine *et al.* (1981) and Scott *et al.* (1990) conducted studies in the large Sarasota Bay environment, rather than creeks and rivers; small enclosed pathways may lead the dolphins to a change in movement patterns. The study site in Harzen (2002) was at the entrance of a simple river system, rather than within a complex tidal inlet and creek system. The Sado River, a single-river estuary that feeds directly into the Atlantic Ocean from a wide mouth of 2 km, was the study site; the observation point of the study was located directly at the meeting point of the river and the ocean. As they found, the dolphins would most likely enter the system with the tidal front, rather than trying to swim against it. A

similar situation was studied in Mendes *et al.* (2002). The Kessock Channel is a narrow system, at 0.5 km wide, but the same idea could be suggested; the strength of the tidal front created by such a small entrance of water from the Moray Firth seemed to give good cause for the dolphins' movement with the tide, rather than trying to swim against it. The difference in complexity of the study environments, and the differences in relative tidal strengths, could be the source of the findings from this study varying from others. However, the relative strength, or potentially speed, of the tides within the three study sites was not determined, and is a point of future research. At such a time, more accurate comparisons could be made with some of the opposing studies. Another area of interest would be to determine which behaviors, if any, are actually impacted by the presence of calves in the group.

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