Shorebird Response to Human-Induced Changes at Three Pinellas County Beaches

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Shorebird Response to Human-Induced Changes at Three Pinellas County Beaches

by

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A thesis submitted in partial fulfillment of the requirements for the degree of
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Abstract

Worldwide, shorebird habitat is being destroyed and degraded by development and sea level rise. Shorebirds depend on availability of pristine, undisturbed coastal habitats for resting and feeding during migration as well as for reproduction. Migratory shorebirds using the East Atlantic Flyway visit the Gulf of Mexico Beaches of Pinellas County, Florida as a stopover site during Fall and Spring migration. In addition to hosting migratory species, Pinellas County beaches are home to several year-round resident species that breed during Summer. Pinellas County is the most densely populated county in Florida, and its Gulf Coast is heavily developed with commercial and residential properties. Additionally, hospitality and tourism are the number one industries in the area, especially along its beaches. Pinellas County is also vulnerable to sea level rise and erosion from storms due to its location. Beach renourishment projects are frequently conducted on the Pinellas Gulf Coast to increase beach width and elevation; and as a result, the beaches have grown wider and more elevated in the past 25 years. In September 2018, an acute outbreak of red tide occurred off the west coast of Pinellas County that lasted for approximately 3 months. In addition to the red tide outbreak, Hurricane Michael, a category 5 storm, made an indirect impact on the Florida Gulf Coast during October 2018. As a result of heavy rain bands from the hurricane, storm surge impacted Pinellas County. In order to examine the effects of a red tide outbreak, a major hurricane, and the extent of development and sea level rise in Pinellas County on shorebird distribution, bird surveys were conducted for 1 year on 3 beaches with varying degrees of development (undeveloped, moderately developed, and highly developed) and human disturbance on the county’s Gulf Coast. Short-term, potentially catastrophic events such as red tide and a major storm did not significantly impact shorebird distribution, but long-term disturbance such as development strongly dictated the abundance of birds as well as species richness at the sites even when created habitat was provided to attract them and beaches
were made wider and higher from renourishment. These results follow a global trend of development as a major contribution to shorebird habitat loss.
Chapter One: Introduction

Globally, shorebirds inhabit rocky and sandy coastlines and feed on benthic crustaceans, worms, and mollusks. Specialized for survival in coastal environments, they exhibit great variability in size, shape and diet preferences that facilitates coexistence of numerous species in the same habitat (Burger et al. 1997). Many species complete long-distance migrations as part of their life cycles, while others stay year-round in subtropical and tropical habitats (Brown et al. 2001). Many such as red knots migrate biannually to and from their breeding grounds in the Arctic -- making several stops at beaches, barrier islands, and mudflats along the world’s flyways to replenish energy by foraging on benthos (Brown et al. 2001).

Migration south occurs in Fall after young have fledged and seasonal change drastically reduces food sources in northern latitudes. Birds return north during Spring for breeding. The prolonged physical effort of migratory flight requires shorebirds to maximize caloric intake and rest before departure and after arrival at wintering grounds (Burger et al. 1997). Because thousands of individuals may arrive simultaneously to wintering grounds, appropriate habitat and food must be available to support them. During the non-breeding season, shorebirds forage constantly to supplement energy reserves for the rigors of migration (Burger et al. 1997). Benthic invertebrates in intertidal zones provide lipids and proteins needed for fat storage and muscle development necessary to sustain extended periods of flight.

Pinellas County, Florida, is a stopover on the Atlantic Flyway, a migratory route that encompasses the entire eastern US, Canada and South America. It is a peninsula separating the Gulf of Mexico to the west from Tampa Bay to the east. The 946 km perimeter of the county is bordered by shallow water habitats and 11 barrier islands on the Gulf coast with high energy beaches and intertidal areas including salt marshes, estuaries, and mangrove swamps. These dynamic and nutrient-rich coastal habitats are ideal environments for over-wintering shorebirds in the non-breeding season from September-
May as well as resident species all year (Sprandel et al. 2000). The barrier islands host many overwintering species such as ruddy turnstones, sanderlings, and black-bellied plovers. Some of these species stay for several months, while others such as piping plovers use the habitat as a temporary stopover before flying farther south. Resident shorebirds include American oystercatchers, willets, and Wilson’s plovers that forage and breed on Gulf beaches year-round (Sprandel et al. 2000).

Many shorebird populations are in peril (Stroud et al. 2006). In the Western Hemisphere alone, over 50% of all shorebird species have experienced population decline (Shaffer-Smith et al. 2018). Globally, there has been a net loss of intertidal and coastal habitats critical for migratory shorebirds to stage, forage, and rest. Many have become degraded by development or have disappeared completely (Zockler et al. 2003). In addition to development, many shorebird habitats have become inundated by rising seas as a consequence of climate change (Galbraith et al. 2002). These alterations to stopover habitats have severely affected migratory populations (Studds et al. 2017) and will certainly impact non-migrant breeding populations as well. Without appropriate habitats for stopover during migration, shorebirds cannot successfully complete their life cycles, and species survival is under threat.

In the 20th century, intertidal sand and mud flats, as well as beachfront, were developed for agriculture, urbanization, and industry (Galbraith et al. 2002). Pinellas County experienced rapid urbanization after World War II. The appeal of beachfront living attracted many new residents and tourists alike to the area and has continued to do so (Xian et al. 2005). Since 1960, the population of Pinellas County has increased by 148% (Xian et al. 2005). Population expansion and increased tourism to the Gulf Beaches over the past 50 years has significantly altered the structure of the coast and adjacent habitats such as estuaries and mudflats--important areas for the survival of wintering migrant as well as breeding shorebirds. Alterations include real-estate and commercial development and beach renourishment, which modify the width and elevation of the shoreline (Pinellas County 2020).

Human disturbance from recreational activities can significantly impact wintering and breeding species that depend on the beach for food and nesting. Increased human activities on beaches physically
distress shorebirds recovering from migration as well as those rearing young during breeding season (Carney and Sydeman 1999). Exhausted migrants arriving at Pinellas County barrier islands require rest and nourishment to restore their energy (Burger et al. 1997). Recreational activities on beaches near the surf where shorebirds forage and rest can alarm them to the point of flushing, and too much disturbance can cause them to abandon preferred foraging locations in favor of less suitable ones away from human activity (Smit and Visser 1993). In addition to potentially harming wintering shorebirds, too much development and human disturbance can affect breeding populations as well. Increased human activities near colonies of nesting shorebirds have caused parental harm to chicks, nest content spillage, and total site abandonment (Carney and Sydeman 1999). Without adequate, undisturbed space on the Gulf coast for migratory shorebirds to rest and refuel and for resident breeders to reproduce, their populations will surely decline.

Another factor threatening shorebird survival and reproductive success is sea level rise associated with global climate change. Rising sea levels caused by expansion of ocean water and melting glaciers will inundate barrier islands, mud flats, and other coastal environments (Galbraith et al. 2002). Relative sea level is rising in Florida. St. Petersburg in Pinellas County has experienced a rise in sea level of approximately 25 cm over the past 70 years (Maul 2015). All climate models project that sea level rise will accelerate in this millennium, and Florida could potentially experience an increase in sea level of up to 2 m (Maul 2015). Should this trend continue, low lying coastal and intertidal areas that migratory and breeding shorebirds depend on for food and reproduction will eventually be covered by water. Conversion of Pinellas County’s intertidal habitats into subtidal habitats due to inundation could reduce the availability of foraging, staging, and breeding spaces available to shorebirds (Galbraith et al. 2002). Sea level rise threatens tidal marshes, mud flats, and barrier islands with flooding and can transform these coastal habitats by significantly reducing available area, altering near-shore depth distributions, and driving changes in estuarine/river interactions (Woodrey et al. 2012).
The current study examines the distribution and seasonality of resident, over wintering and migrant shorebirds on the coast of Pinellas County at three sites representing a gradient of development pressure from intensive to relatively pristine. In addition to long term change related to development and climate change, especially sea level rise, the year-long study was punctuated by two potentially disastrous events for shorebirds--a hurricane and red tide outbreak. This presented a unique opportunity to monitor birds before, during and after these disturbances. The relative importance of short and long term events on shorebird populations and conservation was examined.
Chapter Two: Methods

Study Sites

Shorebird surveys were conducted on foot at 3 sites in Pinellas County, Florida (Clearwater Beach, Indian Shores Beach, and Ft. Desoto North Beach) for the period September 2018 to September 2019 (Figure 1).

Clearwater Beach (27.979637°N, -82.829113°W) is a barrier island located in the middle of the Pinellas County shoreline and flanked to the east by several artificial islands. It is approximately 4 km long and highly developed along its entire length with high-rise rentals and condominiums. Pedestrian activity is nearly continuous even during dawn and evening hours, and throughout the year the beach is populated by tourists. Activity is highest during Spring Break and Summer (St. Pete-Clearwater 2019). Many recreational activities such as jet-skiing, boating, parasailing, and beach-cycling are permitted within close proximity to the beach, and Pier 60 is a popular destination for fishing and other activities. During the study period, pedestrians were observed walking, exercising, sunbathing, fishing, and picnicking at all times, including before sunrise and during inclement weather. Although pets are prohibited on the public beach, many visitors walked and played with off-leash dogs. Restrictions are posted but not strictly enforced regarding beach areas off limits to pedestrians, including dunes. Beachgoers often were observed ignoring postings and walking on dunes and sea oats. Litter is another consequence of high pedestrian traffic. In order to keep Clearwater Beach attractive and inviting to visitors, the city contracts firms to clean litter on the beach and rake the sand daily. A tractor-like vehicle tows a raking device along the surf as it simultaneously tills the sand and removes trash that has washed ashore or was discarded on the beach.
Clearwater Beach was selected for this study to represent a heavily human-influenced site. A small number of man-made dunes provide some natural habitat on the beach, but pedestrians have ignored the signs to keep away, and rules are not enforced. Wave action is moderate to high depending on weather conditions and season. Survey distance was approximately 3.21 km of beach front.

The second site, Indian Shores Beach (27.862750°N, -82.848661°W) is approximately 8.2 km south of Clearwater Beach and is a 4.3 km long barrier island moderately developed with a blend of luxury homes, cottages, high-rise condominiums, and older hotels and rentals. Many properties have retained some degree of natural habitat as part of their appeal including dunes and sea oats. However, human disturbance is moderate throughout the year, and in peak vacation season (Spring Break and Summer), it can become heavy. Indian Shores was selected for this study to represent a moderately disturbed beach, and the degree of human activity varies throughout the year. Pedestrian traffic is low to moderate, and the city enforces stricter rules than Clearwater for types of recreational activities allowed in close proximity to the beach. Survey distance of this study was approximately 4.3 km. Additionally, Indian Shores was selected because it has historically attracted large numbers of migratory shorebirds in winter due to its moderate to high wave action and dynamic littoral zone. Breeding species such as American oystercatchers have also historically used sites around Indian Shores for nesting and rearing young.

Unlike Clearwater Beach, Indian Shores does not attract year-round crowds seeking entertainment but favors visitors and locals wanting a more relaxed beach experience. Pedestrian activity includes walking, beachcombing, fishing, and sunbathing. Due to the majority of development fringing the shoreline being private residences and small resorts, beach restrictions are more strongly enforced. Pedestrians are prohibited from accessing most of the dune habitat on Indian Shores Beach because it is on private property. During the study period, police regularly patrolled heavy tourist areas to enforce posted rules, such as the prohibition of dogs on the beach and consumption of alcohol. Memorial Day, Fourth of July, and Labor Day attracted thousands to the beach at all hours. Although forbidden, many
visitors brought fireworks for the Fourth of July. A breeding colony of Black Skimmers nesting near the 1st Avenue beach access was extremely disturbed by fireworks and pedestrian traffic. Despite presence of local law enforcement, Fish and Game officers, and the local Audubon chapter, birds are disturbed every year.

One additional disturbance on Indian Shores occurred during late September 2018. A beach renourishment project by the US Army Corps of Engineers was completed after several weeks, and many large construction vehicles, pumps, and dredging pipes were moved farther south to Redington Shores Beach. This disturbed many overwintering shorebirds staging on the beach that had just arrived during Fall migration.

The final and southernmost site for the study is the North Beach of Fort Desoto Park (27.635156°N, -82.740111°W) located approximately 35 km south of Indian Shores Beach. Fort Desoto North Beach is one of five small islands located at the southern tip of Pinellas County that are part of the county park system. Wave action is moderate to severe and contributes to the ever-changing shape and extent of the island. While it is an important historical location and attracts tourists and residents year-round, Ft. Desoto Park is large enough that humans and wildlife have limited contact. Park officials have permanently closed a large section of the North Beach for a bird sanctuary because the lagoon has historically attracted hundreds of migratory shorebirds during winter and hosted several breeding colonies during Spring and Summer. There is no development other than basic facilities in the park, and human activity in and near the sanctuary site is prohibited. Here, shorebirds are provided with a place to rest and reproduce as well as forage undisturbed by human activity; therefore, Fort Desoto North Beach serves as the control location that simulates natural conditions least affected by humans. The only buildings present are visitor accommodations such as picnic shelters, a gift shop, and restroom facilities located several meters from the shoreline. Pedestrian activity includes beachcombing, sunbathing, picnicking, and some fishing. As with Indian Shores, activity levels are highest during Spring Break season and Summer (St. Pete Clearwater 2019). All County Park rules and regulations are strictly enforced by park officials and
law enforcement. The designated bird sanctuary is roped off from the public and monitored by 24 hour video surveillance. During the study period, over-wintering shorebirds attracted photographers and bird-watchers to the North Beach sanctuary. While most were respectful of the rules, park officials monitored their activity by patrolling the area regularly. During the 2019 breeding season, the North Beach Sanctuary served as a nesting habitat for American oystercatchers and Wilson’s plovers. While they established territories, nesting efforts were unsuccessful due to predation by coyotes and fish crows. One Wilson’s plover pair successfully nested at another park location; however, the American oystercatchers abandoned their nest and did not attempt again.

Bird Surveys

Bird surveys were conducted approximately 4-5 times monthly at each study site from September 2018-September 2019. Surveys were not performed during inclement weather. At each site, survey routes were walked from northernmost to southernmost point accessible to the public. Each site was surveyed 1-2 times per week during the month. To avoid re-counting, birds were only counted if they were resting or standing on the beach or flying towards the surveyor from the opposite direction. Data collected included number of birds observed by species, temperature, weather conditions, red tide status (during the outbreak period), and estimated human activity. During breeding season, the number of nesting attempts and chicks observed were reported for each site. Data were collected in the morning during low tide when shorebirds were most active, usually from sunrise (7-8 AM) to approximately mid-morning (10-11 AM). Survey times were approximately 1-2.5 hours depending on beach length, between 3-4 km.

Historical Bird Data

In order to understand historical patterns and trends in the distribution of shorebirds in Pinellas County, data from the National Audubon Society Christmas Bird Count Archives (https://netapp.audubon.org/cbcobservation/) were analyzed for decadal trends from the 1980s, 1990s, 2000s, and 2010s. The Christmas Bird Count is a continent-wide bird survey event that has occurred
annually during the last week of December from 1900-present. Participation is open to the public. Individual surveys are performed by 10 or more volunteers in local “count circles,” which have a diameter of 15 miles (24.14 km). There are several hundred counting circles located across the United States, Canada, and South America. After the survey period is over, an estimate of nationwide bird totals of each observed species is calculated by compiling data collected in each counting circle.

Only species observed in the current study during late December 2018-early January 2019 were evaluated, as historical data from other seasons were unavailable. Using data collected during the count years of 1980-2018 from two counting circles located near Clearwater and St. Petersburg Beaches, the average number of birds observed per decade in each family, species, and feeding guild were calculated.

*Human Activity on Beaches*

Bed taxes provide a good estimate of the tourism industry by documenting the number of visitors renting rooms (Thalji 2014). Tourism has been the strongest industry in Pinellas County for the past 50 years (PCHB 2008), with Clearwater Beach generating over 30% of total revenue annually (St. Pete Clearwater 2019). Pinellas County has imposed a 6% Bed Tax on the revenue from hotel rooms and rentals rented for six months or less, with proceeds used for beach clean-up and renourishment, facility maintenance, and community activities. (St. Pete-Clearwater 2019). Clearwater Beach pays contractors to maintain the beach daily with a specialized machine that picks up litter as it simultaneously rakes and tills the sand. Annual and monthly bed tax revenue data were obtained from the Visit St. Pete-Clearwater Industry Partner Site (https://partners.visitstpeteclearwater.com/reporting/bed-tax). The monthly revenue data from September 2018-September 2019 were used as an environmental parameter when evaluating relationships between bird distribution and human activity on the beach.
Development at Beach Habitats

Using the historical maps and spatial analysis tools featured in the Google Earth Pro application, mean beach width, mean dune width, and mean beach elevation were calculated for Clearwater Beach and Indian Shores Beach using images from 1995, 2007, and 2019.

Beach Width

Measurements of beach width were taken using the Add Path tool of Google Earth Pro. Widths of Clearwater and Indian Shores Beaches were measured for 1995, 2007, and 2019 beginning in 1995 and overlaying images of 2007 and 2019. Beach width was measured by drawing a transect on the beach from the landside to the shoreline at the water’s edge. The Google Earth Pro application automatically saves the geographic locations of any created transects, therefore transects drawn on the map from 1995 would appear in the exact location in subsequent years. The mean width (in meters) of Clearwater and Indian Shores Beaches was calculated using measurements from four approximately equally spaced transects drawn on the beaches and obtaining the average width from each year. The locations of the transects were automatically saved from year to year.

Dune Width

The width of each dune on Clearwater and Indian Shores Beaches was also measured using the Add Path tool of Google Earth Pro. One transect was drawn through each dune perpendicular to the shore from the landward to the shoreward extent to measure the width. The transect locations were saved automatically each year.

Beach Elevation

Beach elevations at Clearwater and Indian Shores Beaches were calculated using the Elevation function of the Add Path tool in Google Earth Pro. Fifty meter transects were drawn from land to shore at four approximately equally spaced locations on each beach. Markers were placed digitally on the mid (25
m) and end (50 m) points of each transect. Elevation at each of the marker points was recorded for each year, and the transect locations were saved for each year.

**Dune Area**

At both Clearwater and Indian Shores Beaches, total dune area was calculated by measuring the width and length of each dune for 1995, 2007, and 2019. Using the Add Path tool in Google Earth Pro, transects were drawn through each dune from the landward side to the shoreward side for width and to the northern to southern extent parallel to the shore for length. The lengths and widths of each dune (in meters) were multiplied to obtain dune area. Total dune area was calculated and expressed as a percent of total beach area.

**Beach Area at Ft. Desoto**

As Ft. Desoto North Beach lacks dunes, total beach area was calculated using the Polygon tool to trace the perimeter of the beach using images from 1995, 2007, and 2019. To evaluate land loss over time, the area inside each polygon for each year was calculated and area differences from 1995 through 2019 calculated.

**Climate Data**

In order to evaluate seasonal trends during the study period and the possible impact of Hurricane Michael on shorebirds, climate data including Pinellas County monthly precipitation and temperature were provided by the National Weather Service (www.weather.gov). Hurricane Michael made landfall in the Panhandle near Tyndall AFB on 10 October 2018. While the direct impact was approximately 500 km from Pinellas County, the storm was large enough to develop rain bands that covered the Pinellas Gulf coast bringing storm surge and severe weather (Beven II et al. 2019).
Red Tide Trend Analysis

The Florida FWCC Harmful Algal Bloom Database provided *K. brevis* concentrations offshore of Pinellas County (https://myfwc.com/research/redtide/monitoring/database/). Water samples are routinely collected at several locations inshore and offshore of Florida to detect potential red tide outbreaks. Data are collected weekly, twice monthly, or monthly depending on current *K. brevis* levels. Data from September 2018-September 2019 were used to calculate mean monthly concentrations of *K. brevis* in the Gulf waters (cells/liter) surrounding Pinellas County throughout the study period. Additionally, Pinellas County Solid Waste Services provided total fish kill volume collected for the entire county during September 2018-November 2018. Total mass of fish kill (in tons) was determined at the end of each month. Using these data, total fish kill volume in kg/month was calculated.

Bird Data Analysis

Monthly plots were graphed for each species observed to identify trends in bird distribution over time at the 3 sites. In order to determine if any trends in bird distribution may be related to environmental factors, the monthly plots were graphed beside plots of bed tax (a substitute for tourism and human activity), mean monthly temperature, mean monthly precipitation, and mean monthly *K. brevis* concentration in Pinellas County. Data were subdivided by total number of birds observed per month in each species, family, and feeding guild at each site. Additionally, Kruskal-Wallis tests were performed to determine any significant differences between distributions of total birds, families, species, and feeding guilds at the 3 sites.
Figure 1: Study sites in Pinellas County, Florida
Chapter Three: Results

Bird Response: Historical Winter Data

Although bird data for other seasons were not available, winter bird surveys from the National Audubon Society Christmas Bird Count Archives for 1980-2018 were analyzed by decade. Surveys were performed at two locations on the Gulf coast of Pinellas County; near Clearwater in the north (28.07° N, -82.74° W) and near St. Petersburg in the south (27.80° N, -82.68° W). Historical data were only analyzed for species found in the current study using survey data from 1980-2018. Data for great blue heron were missing from the database. Average number of individuals per decade was calculated for each family and species, and trends were presented for year-round species, winter species, and feeding guilds. A total of 26 species were reported during the current study (Table 1) that were reported from all annual surveys for 1980-2018.

Trends in mean bird numbers on Pinellas County beaches during winter from 1980-present are shown in Figure 2. Data were sourced from The National Audubon Society Christmas Bird Count Archives. From the 1990s-present, mean shorebird as well as mean tern numbers have decreased by over 1,000 individuals. Mean gull numbers have continuously decreased; From the 1980-present, mean gull numbers have decreased by approximately 41,000. Mean wader numbers increased by over 1,000 after the 1980s and have remained relatively stable since. Mean pelican and cormorant numbers increased after the 1990s by over 8,500 but decreased after the 2000s by approximately 18,000. Mean corvids decreased from the 1980s-1990s by approximately 5,000 and remained relatively the same into the 2000s. However, in the 2010s the mean number of corvids increased by almost 1,300 from the previous decade.

Mean shorebirds by species on Pinellas County Beaches during Winter are shown in Figure 3. Year-round species such as American oystercatchers (AMOY), willets (WILL), and Wilson’s plovers
(WIPL) declined from the 1980s-present. Mean number of American oystercatchers declined progressively during this period ($\bar{x} = 198$), the 1990s ($\bar{x} = 181$), 2000s ($\bar{x} = 108$), and 2010s ($\bar{x} = 57$). During the 1980s, mean number of willets was 931. The number remained the same during the 1990s ($\bar{x} = 930$), increased in the 2000s ($\bar{x} = 1036$) and decreased in the 2010s ($\bar{x} = 593$). During the 1980s, mean number of Wilson’s plovers was 51. The number increased in the 1990s ($\bar{x} = 103$) but decreased continuously to the present ($\bar{x} = 36$ in 2000s, $\bar{x} = 22$ in 2010s).

Migratory shorebirds including black bellied plovers (BBPL), dunlin (DUNL), least sandpipers (LESA), marbled godwits (MAGO), piping plovers (PIPL), red knots (REKN), ruddy turnstones (RUTU), sanderlings (SAND), short billed dowitchers (SBDO), and semipalmated plovers (SEPL) displayed great fluctuation in their distribution from the 1980s until present. Some species had high numbers during the 1980s and 1990s but declined in the 2000s and 2010s. Other species gradually increased after the 1990s and declined after 2010. Mean observed numbers have declined since the 1980s for almost all Winter species observed in Pinellas County. During the 1980s, mean number of black bellied plovers was 348. The number increased during the 1990s ($\bar{x} = 529$), but decreased continuously afterwards ($\bar{x} = 324$ in 2000s, $\bar{x} = 233$ in 2010s). During the 1980s, mean number of dunlin was 1404. The number decreased during the 1990s ($\bar{x} = 1176$), increased in the 2000s ($\bar{x} = 1570$), and decreased in the 2010s ($\bar{x} = 877$). During the 1980s, mean number of least sandpipers was 183. The number increased into the 2000s ($\bar{x} = 242$ in 1990s, $\bar{x} = 332$ in 2000s), but decreased after the 2010s ($\bar{x} = 210$). During the 1980s, mean number of marbled godwits was 155. The number remained the same in the 1990s ($\bar{x} = 157$), decreased in the 2000s ($\bar{x} = 87$), and increased in the 2010s ($\bar{x} = 114$). During the 1980s, mean number of piping plovers was 17. The number increased in the 1990s ($\bar{x} = 62$), but decreased after the 2000s ($\bar{x} = 30$ in 2000s, $\bar{x} = 23$ in 2010s). During the 1980s, mean number of red knots was 763. The number increased in the 1990s ($\bar{x} = 833$), but continued to largely decrease after 2000 ($\bar{x} = 286$ in 2000s, $\bar{x} = 230$ in 2010s). During the 1980s, mean number of ruddy turnstones was 236. The number increased slightly in the 1990s ($\bar{x} = 289$), but decreased after 2000 ($\bar{x} = 252$ in 2000s, $\bar{x} = 171$ in 2010s). During the 1980s, mean number of sanderlings
was 320. The number increased during the 1990s ($\bar{x} = 471$), but decreased after 2000 ($\bar{x} = 381$ in 2000s, $\bar{x} = 346$ in 2010s). During the 1980s, mean number of short-billed dowitchers was 1014. The number remained relatively the same in the 1990s ($\bar{x} = 1051$), but decreased after 2000 ($\bar{x} = 767$ in 2000s, $\bar{x} = 286$ in the 2010s). During the 1980s, mean number of semipalmated plovers was 284. The number increased in the 1990s ($\bar{x} = 587$), but decreased after 2000 ($\bar{x} = 401$ in 2000s, $\bar{x} = 275$ in 2010s).

Mean gulls by species on Pinellas County Beaches during Winter are shown in Figure 4. Both winter and year-round gulls have decreased since the 1980s in Pinellas County. During the 1980s, mean number of laughing gulls (LAGU) was 11881. The number greatly decreased after 1990 and continued to decrease into the present ($\bar{x} = 5430$ in 1990s, $\bar{x} = 4929$ in 2000s, $\bar{x} = 4457$ in 2010s). During the 1980s, mean number of ring-billed gulls (RBGU) was 7135. The number greatly decreased after 1990 and continued to decrease into the present ($\bar{x} = 2853$ in 1990s, $\bar{x} = 2349$ in 2000s, $\bar{x} = 1979$ in 2010s). During the 1980s, mean number of herring gulls (HERG) was 899. The number decreased in the 1990s and continued to decrease into the present ($\bar{x} = 221$ in 1990s, $\bar{x} = 166$ in 2000s, $\bar{x} = 49$ in 2010s).

Mean terns by species on Pinellas County Beaches during Winter are shown in Figure 5. Mean numbers of both year-round and migratory terns exhibited a great amount of variation between decades. During the 1980s, mean number of royal terns (ROYT) was 554. The number increased in the 1990s ($\bar{x} = 804$), decreased in the 2000s ($\bar{x} = 652$), and slightly increased in the 2010s ($\bar{x} = 690$). During the 1980s, mean number of sandwich terns (SATE) was 28. The number increased during the 1990s and has continued to do so ($\bar{x} = 95$ in 1990s, $\bar{x} = 120$ in 2000s, $\bar{x} = 187$ in 2010s). During the 1980s, mean number of Forster’s terns (FOTE) was 394. The number increased in the 1990s ($\bar{x} = 656$), but decreased after 2000 ($\bar{x} = 495$ in 2000s, $\bar{x} = 327$ in 2010s).

Mean waders by species on Pinellas County Beaches during Winter are shown in Figure 6. During the 1980s, mean number of great egrets (GREG) was 522. The number increased in the 1990s and remained essentially the same in the 2000s ($\bar{x} = 694$ in 1990s, $\bar{x} = 683$ in 2000s), and decreased slightly in
the 2010s (\(\bar{x} = 620\)). During the 1980s, mean number of snowy egrets (SNEG) was 235. The number increased in the 1990s (\(\bar{x} = 446\)), but decreased continuously after 2000 (\(\bar{x} = 407\) in 2000s, \(\bar{x} = 326\) in 2010s). During the 1980s, mean number of reddish egrets (REEG) was 8. The number increased in the 1990s, remained essentially the same into the 2000s (\(\bar{x} = 25\) in 1990s, \(\bar{x} = 26\) in 2000s), but decreased in the 2010s (\(\bar{x} = 16\)). During the 1980s, mean number of little blue herons (LBHE) was 166. The number decreased slightly in the 1990s (\(\bar{x} = 154\)), but increased after 2000 (\(\bar{x} = 208\) in 2000s, \(\bar{x} = 243\) in 2010s).

Mean pelicans and cormorants by species on Pinellas County Beaches during Winter are shown in Figure 7. During the 1980s, mean number of brown pelicans (BRPE) was 3897. The number decreased slightly in the 1990s (\(\bar{x} = 3424\)), increased in the 2000s (\(\bar{x} = 4821\)), and largely decreased in the 2010s (\(\bar{x} = 1090\)). During the 1980s, mean number of double crested cormorants (DCCO) was 1672. The number decreased slightly in the 1990s (\(\bar{x} = 1439\)), but increased continuously after 2000 (\(\bar{x} = 1746\) in 2000s, \(\bar{x} = 2661\) in 2010s).

Mean number of corvids (fish crows) present on Pinellas County Beaches during Winter are shown in Figure 8. During the 1980s, mean number of fish crows was 8874. The number decreased continuously after the 1990s (\(\bar{x} = 3976\) in 1990s, \(\bar{x} = 3792\) in 2000s), but increased in the 2010s (\(\bar{x} = 5080\)).

Trends in mean year-round resident birds on Pinellas County Beaches during Winter from the 1980s-present are shown in Figure 9. Mean year-round resident numbers have fluctuated between decades. After the 1980s, year-round resident numbers decreased by over 8,100. Numbers increased during the 2000s by approximately 500 and decreased again during the 2010s by over 1,300.

Trends in mean migratory birds on Pinellas County Beaches during Winter from the 1980s-present are shown in Figure 10. Since the 1980s, mean number of individual migratory birds has decreased gradually. From the 1980s to 1990s, numbers decreased by over 2,300. Between the 1990s and
2000s, numbers decreased by over 1,200. Finally, between the 2000s and 2010s numbers decreased by approximately 900.

Trends in mean birds by feeding guild present on Pinellas County Beaches during Winter from 1980-present are shown in Figure 11. Feeding guild designations are sourced from Cornell University’s All About Birds Database. Shorebirds, gulls, and corvids are classified as ground foragers and probers. Mean number of ground foragers ad probers greatly decreased after the 1980s and into the 1990s ($\bar{x} = 17393$ in 1980s, $\bar{x} = 10068$ in 1990s), continued to decrease in the 2000s ($\bar{x} = 8714$), and remained relatively the same in the 2010s ($\bar{x} = 8786$). Pelicans and terns are classified as aerial divers. Mean number of aerial divers increased slightly from the 1980s to 1990s ($\bar{x} = 6393$ in 1980s, $\bar{x} = 7681$ in 1990s) remained the same number from the 1990s to 2000s, but slightly decreased in the 2010s ($\bar{x} = 5103$).

Cormorants are classified as surface divers and mean number decreased between the 1980s and 1990s ($\bar{x} = 1672$ in 1980s, $\bar{x} = 1439$ in 1990s). Mean number of surface divers increased continuously since the 2000s ($\bar{x} = 1764$ in 2000s, $\bar{x} = 2661$ in 2010s). Waders are classified as stalkers and their mean number increased from the 1980s to 1990s ($\bar{x} = 2101$ in 1980s, $\bar{x} = 3196$ in 1990s) and has remained relatively the same since ($\bar{x} = 3277$ in 2000s, $\bar{x} = 3102$ in 2010s).

Species Richness

Species richness at Ft. Desoto North Beach from September 2018-September 2019 is shown in Figure 12. Values varied throughout the year, with the highest value occurring in September 2018 (26). After October 2018, richness decreased to 19 and remained relatively the stable until July 2019, when it was lowest (12). In August, richness increased to 22 and decreased slightly the following month (18).

Species richness of bird groups at Ft. Desoto North Beach is shown in Figure 13. Shorebirds had the highest richness of all groups (12 in September 2018). Shorebird richness decreased gradually after Spring and into Summer, when the lowest richness value occurred in July 2019 (3). By August, it increased to 9 and remained the same the following month. Shorebird richness was highest at this site.
Waders had the second highest group richness (5 in June and August 2019). Their richness remained stable throughout the year but was lowest in April and September 2019 (1). Wader richness was highest at this site. Richness of terns and skimmers also remained relatively stable with the highest value occurring in Spring (4 from February-May 2019). Tern and skimmer richness was equal to that of Indian Shores Beach but greater than Clearwater Beach. Only 2 species of pelicans and cormorants were observed, but both species were constantly present. Pelican and cormorant richness throughout the year was 2, as was the case for all 3 sites. Gull richness was highest during Winter (3 from December 2018-February 2019) and lowest in the late Summer (1 from July-September 2019). Gull richness was the same at all 3 sites (3). Only one corvid species occurred during the study, but was nearly constantly present at all 3 sites throughout the year.

Species richness at Indian Shores Beach from September 2018-September 2019 is shown in Figure 14. This site exhibited moderate variation in richness throughout the year. September 2018 had the highest richness (20). Species richness remained relatively consistent for the rest of the year until decreasing in June (14) and July (12) 2019, the lowest monthly value for the study. In August, it increased to 18 and remained relatively stable.

Species richness of bird groups at Indian Shores Beach is shown in Figure 15. Shorebirds had the highest richness of all groups (9 from September-October 2018). It remained relatively stable throughout the year, but was lowest during late Spring and Summer. Lowest richness was in July (2) but it increased in August and September 2019. Shorebird richness at Indian Shores Beach was slightly lower than at Ft. Desoto North Beach but not as low as Clearwater Beach. Terns and skimmers had the second highest richness (4) and remained relatively constant during the year, with the highest richness occurring in Spring and early Summer and lowest occurring in Winter (3). Tern and skimmer richness was equal to that of Ft. Desoto and higher than Clearwater Beach. Wader richness remained stable throughout the year, the lowest occurred in Winter (1 in December 2018 and January 2019) and the highest during late Spring and Summer (May, July, and August). Wader richness was slightly lower than that of Ft. Desoto North...
Beach, but higher than Clearwater Beach. Gull richness was highest (3) and remained the same from November 2018-May 2019. It was lowest in Summer (1). Two species of pelican and cormorant were constantly present throughout the year, as was one corvid species.

Species richness at Clearwater Beach from September 2018-September 2019 is shown in Figure 16. Clearwater Beach exhibited very little variation in species richness during the year. The highest richness occurred in March 2019 (14) and the lowest in July 2019 (8). Richness remained the same from September 2018 until November (12) and was relatively stable until decreasing slightly in April 2019 (11). It continued to decrease gradually into Summer, but increased in August and September 2019.

Species richness of bird groups at Clearwater Beach from September 2018-September 2019 is shown in Figure 17. Shorebirds, terns and skimmers, and gulls each had a species richness of 3, but terns and skimmers remained the most consistent throughout the year (3 from September 2018- April 2019). Tern richness remained stable for the remaining months. Shorebird richness was lowest at Clearwater Beach, as was tern and skimmer richness. Gull richness remained highest during Winter and early Spring (December 2018-May 2019) and was lowest (1) during Summer from June-September 2019. Only 3 shorebird species were found at the site but their presence was relatively stable throughout the year, except for July when none were observed. Wader richness was 2 and remained relatively the same, except during Winter (December 2018, January and February 2019) and late Summer when none were observed. Wader richness was lowest at Clearwater Beach. Two pelican and cormorant species were constantly present throughout the year, as well as one corvid species.

**Bird Abundance**

Mean monthly bird abundance was calculated for each site from September 2018-September 2019. While highest in species richness, Ft. Desoto North Beach had the lowest abundance of all 3 sites for most months (Figure 18). However, mean abundance was highest in September 2018 at over 740 individuals. With the exceptions of September and another peak in November 2018 ($\bar{x} =426$), mean bird
abundance was relatively stable for the duration of the year at Ft. Desoto North Beach and did not exceed 200 individuals.

Indian Shores Beach had the highest mean bird abundances of all 3 sites despite having moderate species richness (Figure 19). It peaked in October 2018 at over 670 individuals, followed by March (\( \bar{x} = 624 \)) and August 2019 (\( \bar{x} = 602 \)). Mean abundance was lowest in December 2018 (\( \bar{x} = 242 \)). Abundance values varied throughout the year, with the lowest in winter from December 2018-January 2019 (\( \bar{x} = 242, \bar{x} = 236 \)) and in late Spring-early Summer from April-May-June 2019 (\( \bar{x} = 264, \bar{x} = 304, \bar{x} = 283 \)).

While displaying the lowest species richness, Clearwater Beach had intermediate mean bird abundance that varied throughout the year (Figure 20). The highest mean abundance values were in October (\( \bar{x} = 349 \)) and November 2018 (\( \bar{x} = 287 \)). Mean abundance values decreased into December and January (\( \bar{x} = 93, \bar{x} = 131 \)). Abundance increased in February and March 2019 (\( \bar{x} = 220, \bar{x} = 221 \)) but were lowest in April (\( \bar{x} = 82 \)) and did not exceed 150 individuals until August 2019 (\( \bar{x} = 164 \)).

A Kruskal-Wallis test was used to examine differences in the distributions of birds at each site (Table 2). At the significance level \( P = .05 \), species richness at Clearwater Beach was significantly lower than at the other sites. There were no significant differences in species richness between Indian Shores Beach and Ft. Desoto North Beach. Overall bird abundance was significantly lower at Clearwater beach than at Indian Shores Beach, and was significantly higher at Indian Shores Beach than at Ft. Desoto North Beach.

Family Abundance

Ten bird families were recorded in this study (Table 1). The mean monthly abundances of each for the three sites were recorded for September 2018-September 2019. The Kruskal-Wallis test was used to determine significant differences, if any, in the distribution of families between sites over the year (Table 3).
All 10 families were seen during the study period at Fort Desoto North Beach (Figure 21). During September 2018, gulls (Laridae) were the most abundant group at over 700 individuals, with a secondary peak in November. After that, numbers rapidly decreased and did not exceed 70 individuals for the rest of the study. The second most abundant family at this site was terns (sub-family Sterninae), which varied in abundance but were present in large numbers throughout the year. Skimmers (Rynchopidae) were most abundant in early Fall and least abundant in Winter. Sandpipers and plovers (Scolopacidae and Charadriidae) were most abundant in late Fall and Winter, but numbers decreased in Spring and were lowest during Summer. Oystercatchers (Haematopodidae) were present intermittently during the year. Pelicans, cormorants, and waders (Pelicanidae, Phalacrocoricidae and Ardeidae) were present year-round in small numbers with little inter-month variation. Crows (Corvidae) were present during most of the year but were most abundant during Summer and early Fall.

The families most abundant in Fall were gulls, terns, skimmers, waders, plovers, and crows. While gulls, terns, crows, and waders exhibited similar patterns across all 3 sites, skimmers did not congregate in large numbers (> 100) during Summer at Ft. Desoto North Beach, unlike Indian Shores Beach. Neither skimmers nor plovers appeared at Clearwater Beach. Gull populations were low throughout the study period with the exceptions of September and November 2018 ($\bar{x}_9 = 719$ in September, $\bar{x}_9 = 406$ in November). Their mean abundance did not exceed 70 individuals for the rest of the year. Tern abundance was variable throughout the year. Their mean abundance was highest in September 2018 ($\bar{x}_9 = 313$) but numbers fluctuated monthly from just under 100 to around 200 individuals. In Spring, numbers gradually decreased until May 2019, when abundance steadily increased into the Summer months. Abundance of skimmers peaked in September 2018 ($\bar{x}_9 = 248$) but rapidly decreased afterwards. Mean abundance did not exceed 50 individuals for the rest of the study period. Waders were present year-round with little inter-month variation and <10 individuals seen per month, on average. They were most abundant in September 2018 ($\bar{x}_9 = 4$). Abundance of plovers peaked in November 2018 ($\bar{x}_9 = 25$) and
gradually decreased for the remainder of the study period. Crows were present at low numbers (\( \bar{x} \leq 20 \)) for most of the year. They were most abundant in September 2018 (\( \bar{x} = 20 \)) and least abundant during Spring.

Sandpipers were most abundant in Winter. Their abundance peaked in January 2019 (\( \bar{x} = 34 \)) and gradually decreased into the Summer months. This pattern was similar for sandpipers at Clearwater Beach, but not Indian Shores Beach where they were most abundant in Fall.

Oystercatchers, pelicans, and cormorants were present year-round and did not exhibit any definite seasonal trends, as was also the case at Indian Shores Beach. Oystercatchers were not present at Clearwater Beach; however, pelicans and cormorants exhibited similar patterns there. Oystercatchers were most abundant in September 2018, January 2019, and March 2019 (\( \bar{x} = 2 \)) but were not present in December 2018, February 2019, or July-September 2019. Pelicans and cormorants were both regularly present during the entire study period with little variation between months.

As with Ft. Desoto North Beach, all 10 bird families were also observed at Indian Shores Beach (Figure 22). In October 2018, gulls (Laridae) were the most abundant family (\( \bar{x} = 1008 \)). However, for the remainder of the year, their mean abundance was relatively stable and did not exceed 400 individuals. The second most abundant family was terns (sub-family Sterninae), which were present year-round and most abundant in mid-Spring with a smaller peak in Summer. Sandpipers and plovers (Scolpicidae and Charadriidae) both peaked during Fall and Spring, with Scolpicidae most abundant in Fall and Charadriidae most abundant in Spring. Oystercatchers (Haematopodidae) were present intermittently throughout the year. Skimmers (Rynchopidae) were most abundant in Summer. Pelicans and cormorants (Pelicanidae and Phalacrocoricidae) were present year-round in moderate numbers and did not show a distinct seasonal pattern, although pelicans did somewhat increase during Spring. Waders (Ardeidae) were present in small numbers throughout the year but most were abundant in Fall. Crows (Corvidae) were also present year-round and were most abundant in Summer.
Gulls, waders, and sandpipers were most abundant in Fall. Similar to Clearwater Beach, gulls were constantly present in large numbers throughout the study period (200<\bar{x}<400) and were most abundant in October 2018 (\bar{x}= 1008). With the exception of this large peak, gull numbers remained relatively stable. Waders were most abundant in September 2018; however, numbers decreased rapidly after October and remained low for the rest of the study period. Waders were most abundant in Fall at all 3 sites. Sandpipers displayed minor fluctuations during the study period. They were most abundant in September 2018 (\bar{x}= 63) and were least abundant during Summer. Sandpipers were least abundant in Summer at all 3 sites.

Plovers and terns were most abundant in Spring. Plovers were regularly present in small numbers (\bar{x} \leq 10) during Fall and Spring, peaking in March (\bar{x}= 10), but were not present during Summer. Plovers were also least abundant in Summer at Ft. Desoto North Beach; however, they were absent from Clearwater Beach during the entire study period. Terns were constantly present in large numbers throughout the year, as was the case at all 3 sites. Their abundance peaked in March (\bar{x}= 577) and was lowest in late Spring-early Summer.

Skimmers and crows were most abundant in Summer, especially July 2019 (\bar{x}= 300 for skimmers, \bar{x}= 24 for crows). Skimmers did not appear in late Fall or Winter, unlike as seen at Ft. Desoto North Beach, and were absent from Clearwater Beach during the entire study period. Crows were present year-round but most abundant in Summer and least in Winter.

Oystercatchers, pelicans, and cormorants did not exhibit any definite seasonal trends. Oystercatchers were most abundant September-October 2018 and March 2019 (\bar{x}= 1) but did not appear for the rest of the study period. Pelicans were present all year in moderate numbers (\bar{x}<60) with a slight peak in March; however, there was very little inter-month variation between seasons. Cormorants were present all year in small numbers with little change in mean monthly abundance.
Unlike Ft. Desoto North Beach and Indian Shores Beach, Clearwater Beach hosted only 7 bird families (Figure 23). Gulls (Laridae) were the most abundant family, followed by terns (sub-family Sterninae). Both families were present year-round and most abundant in Fall, with Laridae peaking in October 2018 and Sterninae peaking in November 2018. Sandpipers (Scolopacidae) were most abundant in late-Winter and least abundant in Summer. Pelicans (Pelicanidae) and cormorants (Phalacrocoricidae) were present year-round. Both displayed little inter-month variation and were most abundant in mid-Summer. Pelicanidae also experienced a peak in late Fall. Waders (Ardeidae) were intermittently present throughout the study period and most abundant in October 2018. Corvidae were present in moderate numbers throughout the year (\( \bar{x} \leq 42 \)) and they were most abundant in October 2018 and during Summer.

Gulls, terns, waders, and crows were most abundant in Fall. Gulls were present year-round in large numbers but most abundant in October 2018 (\( \bar{x} = 399 \)). There was an additional, smaller peak in Spring during February and March 2019 (\( \bar{x} = 223 \) in February, \( \bar{x} = 226 \) in March), and numbers remained relatively stable for the rest of the year. Terns were also present year-round in large numbers, and most abundant in November 2018 (\( \bar{x} = 272 \)). After November, there was little inter-month variation in their abundance; however, there was a slight peak during Spring. Waders were present intermittently and in small numbers during the entire study period. They were most abundant in October 2018 (\( \bar{x} = 6 \)). Finally, crows were present year-round in moderate numbers (\( \bar{x} < 50 \)). They were most abundant in October 2018 (\( \bar{x} = 42 \)) and were also abundant in Summer.

Sandpipers were most abundant in Winter. Their abundance peaked in February 2019 (\( \bar{x} = 58 \)). In the following months, they decreased progressively and were least abundant in Summer.

Cormorants were most abundant in Summer, peaking in July 2019 (\( \bar{x} = 15 \)). Their mean abundance did not exceed 20 individuals for the entire study period; however, they were present year-round.
Pelicans were present year-round in moderate numbers (\( \bar{x} < 40 \)) and displayed little inter-month variation. There were two minor peaks in abundance during late Fall and mid-Summer; however, there was no definite seasonal pattern in their abundance.

To test for significant differences in the distribution of bird families at the 3 sites, a Kriskal-Wallis test was performed using monthly abundances of individuals in each of the 10 families seen during the study period (Table 3). At the significance level of \( P = .05 \), sandpipers were significantly more abundant at Indian Shores Beach than at Clearwater Beach, but not Ft. Desoto North Beach. There were significantly fewer Plovers at Clearwater Beach than at the other 2 beaches, where there were no differences in their distribution. Similar to plovers, oystercatchers were also significantly fewer at Clearwater Beach than the other 2 sites. While there were no significant differences between Indian Shores and Clearwater Beach in the distribution of gulls, they were significantly lower at Ft. Desoto North Beach than at the other beaches. Terns were evenly distributed at all 3 sites. As seen with plovers and oystercatchers, skimmers and waders were significantly lower at Clearwater Beach than at the other 2 sites, where there were no differences. Both pelicans and cormorants were distributed significantly lower at Ft. Desoto North Beach than at the other 2 sites where there were no differences in distribution.

**Species Abundance**

Mean monthly abundances of major species in each bird family observed at Ft. Desoto North Beach from September 2018- September 2019 are shown in Figure 24. The family with highest species richness was Scolopacidae (sandpipers) with 6 species; sanderlings (SAND), ruddy turnstones (RUTU), short-billed dowitchers (SBDO), willets (WILL), marbled godwits (MAGO), and red knots (REKN). Ft. Desoto North Beach had the greatest number of sandpiper species of the 3 sites. Additionally, Ft, Desoto North Beach had the greatest number of Ardeidae (wader) species of the 3 sites, which included great egrets (GREG), little blue herons (LBHE), reddish egrets (REEG), and snowy egrets (SNEG). Charadriidae (plover) species richness were also highest at Ft. Desoto North Beach, which included black belliied plovers (BBPL), semipalmated plovers (SEPL), and Wilson’s plovers (WIPL).
Sanderlings were the most abundant sandpiper at all 3 sites. They were found in greatest numbers during Fall and Winter. Ruddy turnstones were least abundant at Ft. Desoto North Beach. They had a large peak in November 2018 ($\bar{x} = 28$) but were found in small numbers (<10) for the rest of the study period and did not appear in Summer. Short-billed dowitchers were found only at Ft. Desoto North Beach. They peaked in November ($\bar{x} = 22$) and were intermittently seen in small numbers through Winter and early Spring. They did not appear from April-July 2019 but returned in late Summer. Willets occurred in small numbers year-round and peaked in January 2019 ($\bar{x} = 28$). They appeared at all 3 sites. Marbled godwits were found only at Ft. Desoto North Beach. They peaked in November 2018 ($\bar{x} = 22$) but were not seen again from January 2019-September 2019. Red knots were least abundant at Ft. Desoto North Beach. They were seen in small numbers during Fall, Winter and late Spring (<10). They were absent until the end of summer, when their abundance was highest ($\bar{x} = 21$ in August 2019). Red knots were highly abundant in early Fall 2018 at Indian Shores Beach; however, they rapidly decreased after October and were not present again until Summer in small numbers. They were absent from Clearwater Beach.

The most abundant plovers at Ft. Desoto North Beach and Indian Shores Beach were black bellied plovers. They peaked in November at Ft. Desoto North Beach ($\bar{x} = 47$), steadily decreased into Spring, and did not appear again until late Summer. Semipalmated plovers appeared in small numbers from Fall-Winter ($\bar{x} <10$), gradually decreased in Spring, and did not appear again for the rest of the study period. Both black bellied and semipalmated plovers were most abundant at Ft. Desoto North Beach. Wilson’s plovers appeared only at Ft. Desoto North Beach, where they were found intermittently in very small numbers ($\bar{x} < 5$) throughout the year.

Laughing gulls (LAGU) were the most abundant gull species at all 3 sites. They were most abundant at Ft. Desoto North Beach in November 2018 ($\bar{x} = 601$) and September 2018 ($\bar{x} = 539$), but numbers rapidly decreased afterwards and remained low ($\bar{x} < 75$) for the duration of the study period. The second most abundant gulls were ring-billed gulls (RBGU), which peaked in February ($\bar{x} = 14$) and decreased into late Spring-early Summer. They did not appear after June 2019.
Sandwich terns (SATE) were the most abundant tern at Ft. Desoto North Beach. They were most abundant in Fall, peaking in November 2018 ($\bar{x} = 206$) and again in May 2019 ($\bar{x} = 114$) but were present in moderate numbers (< 120) throughout the year. Royal terns (ROYT) were the second most abundant tern, also peaking in November 2018 ($\bar{x} = 100$). Their abundance decreased after November 2018; and mean numbers remained < 100 for the rest of the study period. As was the case at the other 2 sites, Forster’s terns (FOTE) were the least abundant tern at Ft. Desoto North Beach. However, their individual abundance was highest there, where they peaked in January 2019 ($\bar{x} = 95$) and steadily decreased into Summer.

Black skimmers (BLSK) were most abundant at Ft. Desoto North Beach during Fall, peaking in September 2018 ($\bar{x} = 248$). However, they decreased during Winter and mean numbers were <50 for the rest of the study period.

Wader species were abundant in small numbers throughout the year; however, great egrets were the most abundant species in September 2018 ($\bar{x} = 3$). Snowy egrets were present in all months except April and September 2019. Reddish egrets and little blue herons occurred only at Ft. Desoto North Beach. No species displayed any definite trends in abundance.

Neither pelicans (Pelicanidae) nor cormorants (Phalacrocoracidae) exhibited any seasonal patterns or trends during the study period and were present in small numbers year-round at all 3 sites. Brown pelicans (BRPE) were most abundant in November 2018 ($\bar{x} = 10$) and double crested cormorants (DCCO) were most abundant in September-October 2018 and April 2019 ($\bar{x} =3$). Ft. Desoto North Beach had the lowest abundance of both brown pelicans and double crested cormorants.

Fish crows (FICR) were found at all 3 sites and were the only Corvid species observed during the study period. They were slightly less abundant at Fort Desoto North Beach than at Indian Shores Beach, peaking in September 2018 ($\bar{x} = 20$). They were present in small numbers for most of the year.
Oystercatchers were most abundant at Ft. Desoto North Beach; however, they were present intermittently throughout the year in very small numbers ($\bar{x} \leq 3$).

Indian Shores Beach mean monthly prominent species abundances are shown in Figure 25. As seen with Ft. Desoto North Beach, Scolopacidae (sandpipers) had the highest species richness (4); sanderlings, ruddy turnstones, willets, and red knots. Indian Shores Beach had the second highest number of sandpiper species of the 3 sites. Both Ardeidae (waders) and sub-family Sterninae (terns) were represented by 3 species, and Charadriidae (plovers) had 2, both fewer than at Ft. Desoto North Beach. Laridae had 2 species at all 3 sites, and Pelicanidae, Phalacrocoracidae, and Corvidae were represented by a single species.

Sanderlings were the most abundant sandpiper species at Indian Shores Beach, peaking in September 2018 ($\bar{x} = 198$). Overall, sanderling abundance was highest at this site. Their numbers decreased gradually into Spring, and they were not present for most of Summer. In August 2019, sanderling abundance slightly increased. Red knots were very abundant in September 2018 ($\bar{x} = 129$), but drastically decreased in October and were not observed again until late Summer 2019 and only in very small numbers ($\bar{x} <10$). While they were most abundant at Indian Shores Beach, they appeared in large groups for only a brief period. Ruddy turnstones were most abundant at Indian Shores Beach. Their numbers peaked in Fall, gradually decreased into Spring, and they were not present for most of Summer. Similar to the pattern observed in sanderlings, their numbers slightly increased in August 2019. Willets were most abundant at Indian Shores Beach, slightly more so than Ft. Desoto North Beach. Their numbers peaked in Fall, but they were present in moderate numbers year-round.

As seen with Ft. Desoto North Beach, black bellied plovers were the most abundant plover at Indian Shores Beach. Their numbers increased gradually from Fall into Spring, when they peaked in March ($\bar{x} = 19$). Their numbers decreased progressively as Summer approached, and they did not appear again until August 2019. Semipalmated plovers peaked in October 2018 ($\bar{x} = 5$) and progressively decreased through Winter and Spring. They were not present in Summer.
Laughing gulls were the most abundant gull at Indian Shores Beach, peaking in October 2018 ($\bar{x} = 756$), and they were present in high numbers all year. Their abundance was highest at this site. Ring billed gulls were most abundant in late Winter and early Spring, peaking in February 2019 ($\bar{x} = 35$). They did not appear for the rest of the study period after May 2019.

Royal terns were most abundant at Indian Shores Beach, where they were also the most abundant tern species. While they were present in large numbers year-round, numbers peaked in March ($\bar{x} = 255$). Sandwich terns were also most abundant at this site and were the second most abundant tern species. They displayed a very similar pattern to royal terns and peaked in the same months; however, they were most abundant in late Summer 2019. Forster’s terns peaked in late Fall-Winter and decreased gradually into Spring. They were not present for most of Summer and numbers increased gradually in August 2019.

Black skimmers were most abundant in Summer, peaking in July 2019 ($\bar{x} = 300$). They were most abundant at Indian Shores Beach; however, they did not appear from October 2018-January 2019.

Similar to the other sites, waders did not show any seasonal trends during the study period at Indian Shores Beach. However, snowy egrets were fairly abundant from September-October 2018, peaking in September ($\bar{x} = 22$). After October, numbers drastically decreased and were stable for the rest of the study period. The abundance of the other two species, great egrets and great blue herons (GBHE), remained low ($\bar{x} <5$) for the entire year.

As seen at both Ft. Desoto North Beach and Clearwater Beach, brown pelicans and double crested cormorants were present year-round in moderate numbers and did not show seasonal patterns. However, brown pelicans were most abundant at Indian Shores Beach, peaking in March ($\bar{x} = 55$).

Fish crows were present in small numbers year-round and were most abundant in Summer, peaking in July 2019 ($\bar{x} = 24$). American Oystercatchers were present intermittently throughout the year in very small numbers. They were slightly less abundant at Indian Shores Beach than at Ft. Desoto North Beach.
Clearwater Beach mean monthly species abundances are shown in Figure 26. Overall species richness was lowest at Clearwater Beach. Sandpiper richness was lowest at this site (3), as was wader richness (2). Plovers, skimmers, and oystercatchers did not appear at any time during the study period at Clearwater Beach.

While sanderlings were the most abundant sandpiper at Clearwater Beach, their abundance was lowest at this site. Numbers peaked in Winter and decreased into Spring. They were not present during Summer. The second most abundant sandpiper species was ruddy turnstones; however, their abundance was also lowest at Clearwater Beach. They were most abundant in Fall and Winter and decreased gradually into Spring. Willets were least abundant at Clearwater Beach but were present in small numbers ($\bar{x} < 10$) year-round.

Laughing gulls were present in large numbers year-round but were most abundant in Fall, peaking in October 2018 ($\bar{x} = 299$). Numbers decreased the following month and remained stable for the remainder of the study. Ring billed gulls peaked in Winter and steadily decreased into Spring. They were not present during Summer.

Abundance of royal, sandwich, and Forster’s terns was lowest at Clearwater Beach. Royal and sandwich terns were present year-round and followed similar patterns, with peaks in Fall and Spring. Sandwich terns were most abundant in September 2018 ($\bar{x} = 142$), and royal terns were most abundant in September 2018 and September 2019 ($\bar{x} = 96$, $\bar{x} = 93$). Forster’s terns gradually increased from Fall into Spring, peaking in February and March 2019 ($\bar{x} = 14$, $\bar{x} = 12$) then decreasing into Summer. They did not appear from May-August 2019.

Waders did not exhibit definite seasonal patterns; however, snowy egrets were relatively abundant in October 2018 ($\bar{x} = 3$). In the following months, they appeared intermittently for the rest of the study period. Similarly, great egrets peaked in September 2018 ($\bar{x} = 1$), and they made intermittent appearances for the rest of the study period.
Double crested cormorants were most abundant at Clearwater Beach. While neither they nor brown pelicans displayed any seasonal patterns, double crested cormorants peaked in July 2019 ($\bar{x} = 15$). Both species were present year-round in moderate numbers, with brown pelicans peaking in November ($\bar{x} = 32$).

Fish crows were most abundant at Clearwater Beach and present in moderate numbers year-round. Their abundance peaked in October 2018 ($\bar{x} = 42$), and there was an additional peak during Summer.

Kruskal-Wallis tests were performed to examine differences in the distributions of dominant species observed at each site during the year (Table 4). At the significance level of $P = .05$, ruddy turnstones and sanderlings were both significantly lower at Clearwater Beach than Indian Shores Beach. Sanderlings were significantly lower at Ft. Desoto North Beach than at Indian Shores Beach. There were significantly fewer willets at Clearwater Beach, but there were no significant differences between the other 2 sites. Black bellied plovers and semipalmated plovers were significantly fewer at Clearwater Beach than at the other 2 beaches, which were similar in numbers. Oystercatchers also displayed this pattern. Laughing gulls were significantly lower at Ft. Desoto North beach than at the other sites, which displayed similar numbers. Ring billed gulls were evenly distributed between all sites. Forster’s terns were significantly higher at Ft. Desoto North Beach than at Clearwater Beach, but not significantly different from Indian Shores Beach. Royal terns displayed significantly higher numbers at Indian Shores Beach than at Ft. Desoto North Beach, but there were no significant differences between their distribution between the other sites. Sandwich terns were evenly distributed among the 3 sites. Black skimmers were significantly lower at Clearwater Beach than at the other sites, where there were no differences in their distribution. Brown pelicans and double crested cormorants were significantly lower at Ft. Desoto North Beach than at the other 2 beaches, where there were no differences in either of their distributions. Fish crows displayed a significantly higher distribution at Clearwater Beach than at Ft. Desoto North Beach, but there were no differences elsewhere.
Mean monthly abundances of birds by feeding guild were calculated for each of the 3 beaches from September 2018-September 2019 (Figure 27). Guild classifications follow Cornell University’s All About Birds website, www.allaboutbirds.org (2020). Ground foragers and probers hunt using visual or tactile methods to find prey on or below the ground. Aerial divers fly over water and pursue prey by diving from great heights. Stalkers quietly wait for prey to be in striking range before spearing with their bills. Surface divers swim just below the water’s surface to hunt for prey. Aerial foragers are tactile feeders and fly just above the water’s surface. Classifications are shown in Table 5.

Ft. Desoto North Beach hosted all 5 feeding guilds, as did Indian Shores Beach. Aerial divers were the most abundant guild at all 3 beaches, and present throughout the year. They were most abundant in Fall, but additionally peaked in late Spring and late Summer. Ground foragers and probers were the second most abundant guild, peaking in Fall and decreasing in Spring and Summer. The other 2 sites showed a similar pattern. Aerial foragers were also highly abundant in Fall, peaking in September 2018 ($\bar{x}$ = 248); however, they progressively decreased afterwards, and mean abundance remained low for the rest of the study. Surface divers and stalkers at all 3 sites were present in low numbers throughout the year and did not display seasonal patterns.

Indian Shores Beach also hosted 5 feeding guilds. As seen with the other 2 beaches, aerial divers were the most abundant guild. Here, they were most abundant in March 2019 ($\bar{x}$ = 488) as well as peaking in Summer. The second most abundant guild present throughout the year were ground foragers and probers, as seen with the other beaches. Although present year-round, they peaked in Fall and gradually decreased for the rest of the year. Aerial foragers were most abundant in Summer and did not appear during late Fall or Winter, unlike at Ft. Desoto North Beach where they were present all year. As was the case with the other 2 sites, stalkers and surface divers were constantly present year-round in low numbers with little inter-month variation.
Unlike the other 2 sites, Clearwater Beach only hosted 4 feeding guilds. Aerial foragers were not present at any time during the study period. As with the other 2 beaches, aerial divers were the most abundant guild, peaking in Fall. The second most abundant guild were ground foragers and probers, which peaked in October 2018 (\( \bar{x} = 205 \)) and remained relatively stable throughout the year, slightly decreasing in late Spring and Summer. Surface divers and stalkers remained present in low numbers during the entire year.

Results of Kruskal-Wallis tests performed on feeding guilds are shown in Table 6. Ground foragers and probers were significantly higher at Indian Shores Beach than at Ft. Desoto North Beach, but there were no significant differences between any other sites. Aerial divers displayed no significant differences in their distribution between sites. Distribution of surface divers was significantly lower at Ft. Desoto North Beach than at the other beaches, but Indian Shores Beach and Clearwater Beach were not significantly different. Both stalkers and aerial foragers had significantly lower numbers at Clearwater Beach than at the other sites; however, the other beaches did not display significant differences.

**Bird Response to Environmental Parameters**

The bird families that experienced abundance peaks at Fort Desoto North Beach during the months of highest offshore *Karenia brevis* concentrations (September 2018-November 2018) were sandpipers (Scolopacidae), plovers (Charadriidae), gulls (Laridae), pelicans (Pelicanidae), and crows (Corvidae) (Figure 28). Sandpiper and plover abundance increased together from October-November. Following the outbreak period, their abundance remained stable until decreasing in the Spring. Gulls, crows, and pelicans rapidly increased from October-November. Following the outbreak, gull numbers remained low for the remainder of the study period. As was the case at all three sites, gulls were most abundant during months of highest offshore *K. brevis* concentrations. Both pelican and crow abundance stabilized during the months after the outbreak, and both displayed secondary peaks in Summer. Waders, skimmers, and terns decreased after September but stabilized after November. Due to the large amount
of daily variability in bird numbers, no changes in family abundance in response to offshore *K. brevis* concentrations were considered statistically significant.

Gull and crow abundances at Indian Shores Beach increased rapidly during the red tide outbreak from September-October 2018 (Figure 29). When offshore *K. brevis* concentrations decreased, gull abundance decreased and remained stable for the remainder of the study. Crow abundance decreased following the outbreak and their numbers remained low until Summer, when abundance peaked. Plover abundance steadily increased during the outbreak period from September-October, but decreased in November. Pelican abundance also increased slightly in November towards the end of the outbreak period but stabilized in December. Oystercatchers and waders decreased in abundance after October. As with Fort Desoto North Beach and Clearwater Beach, daily variability in bird numbers were relatively high, which affected monthly distributions of bird families. Therefore, no changes in family abundance in response to offshore *K. brevis* concentrations were considered statistically significant at Indian Shores Beach.

At Clearwater Beach, gull, crow, wader, and sandpiper abundance increased during the months of highest offshore *K. brevis* concentrations (Figure 30). Gull, crow, and wader numbers decreased rapidly after October 2018, while sandpipers remained stable until December. Pelican and cormorant abundance increased at the end of the outbreak period in November 2018. Both families remained stable until mid-summer when their numbers increased. No statistically significant changes in family abundances were observed due to the high amount of daily variation affecting monthly distributions.

Bird families at Fort Desoto North Beach that increased in abundance during peak Summer tourism months (June-July 2019) were waders and crows (Figure 31). Waders decreased after August and crows decreased after July. Pelicans numbers also slightly increased in June, remained stable through July, and decreased after August. Oystercatchers and skimmers experienced a small increase in abundance during March, when tourists are most abundant on Pinellas Beaches for Spring Break season. Similar to the red tide parameter, no statistically significant results were observed in bird family
distributions at Fort Desoto North Beach in response to bed tax revenue (serving as human activity on the beach) because of large daily variation in bird numbers.

At Indian Shores Beach (Figure 32), pelicans, terns, plovers, sandpipers, and oystercatchers peaked in abundance during Spring Break season (March-April 2019). Crows, cormorants, and skimmers were most abundant during the Summer tourism months from June-July 2019. During this time, gulls and terns experienced secondary abundance peaks. Due to large daily variation in bird numbers, no statistically significant changes were observed in bird family distributions in response to human activity at Indian Shores Beach.

At Clearwater Beach, the bird families that increased in abundance during the Spring Break season March-April 2019 were crows, gulls, and waders (Figure 33). Tern abundance also slightly increased. During Summer tourism months June-July, pelicans and cormorants peaked in abundance, while waders experienced a secondary peak. As was the case with the other two sites, daily variation in bird abundance affected monthly distributions. Therefore, no changes in bird response to human activity were considered statistically significant at Clearwater Beach.

At Fort Desoto North Beach, sandpipers and plovers decreased in abundance as the temperature increased (Figure 34). Crow, pelican and cormorant abundance increased steadily as temperature increased. Waders were most abundant during the warmest months May-September 2019. Oystercatchers became more abundant as the temperature began to increase, but numbers decreased rapidly after May 2019. Tern abundance also peaked during May 2019, but decreased in June then steadily increased into the Summer. Gull and skimmer numbers were stable. As with the other parameters at this site, no changes in bird family distribution in response to changes in temperature were considered significant due to the large amount of daily variation in bird numbers.

Similar to Fort Desoto North Beach, both sandpipers and plovers decreased in abundance at Indian Shores Beach as temperature increased (Figure 35). Skimmer and crow numbers increased rapidly
as temperature increased, while pelicans, cormorants, and terns increased steadily. Waders and gulls remained stable, as was the case with Fort Desoto North Beach. No changes in abundance in response to temperature were considered statistically significant due to daily variation in bird abundance.

At Clearwater Beach and the other two sites, sandpipers were the only family to decrease as temperature increased (Figure 36). Pelicans, cormorants, and crows rapidly increased in abundance following the onset of warmer temperatures from March-June 2019, while terns, waders, and gulls increased steadily. As with the other two sites, none of the changes in bird family abundance were considered statistically significant in response to changes in temperature.

Development

Based on historical images and spatial analysis tools in Google Earth Pro, mean widths for each dune on Clearwater (Figure 37) and Indian Shores (Figure 38) Beaches were measured perpendicular to the shore for 1995, 2007, and 2019. A mean dune width was then calculated for each beach each year. Mean dune width at both Clearwater and Indian Shores Beaches has increased over the years. At Clearwater Beach, mean dune width in 1995 was 8.69 meters (σ=8.944), increased to 11.7 meters in 2007 (σ=14.925), and was 22.5 meters in 2019 (σ=16.840). Mean dune width for Indian Shores Beach was 7.5 meters in 1995 (σ=7.177), 12.9 meters in 2007 (σ=6.806), and continued to increase to 18.4 meters in 2019 (σ=8.105). The width of Clearwater (Figure 39) and Indian Shores (Figure 40) Beaches was measured perpendicular to the shore using historical images and the spatial analysis tools in Google Earth Pro for 1995, 2007, and 2019. Mean beach width was then calculated for each year at both beaches. Beach width has increased at both sites since 1995. In 1995 at Clearwater Beach it was 115.4 meters (σ=23.103), essentially remained the same (117.1 meters) in 2007 (σ=44.533) but increased in 2009 to 134.3 meters (σ=48.533). The beach width at Indian Shores was less than half that of Clearwater Beach in 1995 (47.3 meters, σ=20.107), increased in 2007 (70.2 meters, σ=22.058) and remained relatively unchanged in 2019 (73.7 meters, σ=20.912).
Mean beach elevation was calculated for Clearwater (Figure 41) and Indian Shores (Figure 42) Beaches using spatial analysis tools and historical images in Google Earth Pro. At each site, a 50 m transect was drawn perpendicular to the shoreline. Elevation was measured at the midpoint (25 m) and endpoint (50 m) of the transects, and the mean elevation was calculated for each beach. Clearwater Beach mean elevation in 1995 was 1.07 m (σ=0.216). It remained relatively unchanged in 2007 (1.07 m, σ=0.216), and 2019 (0.9144 m, σ=0). Indian Shores Beach mean elevation in 1995 was 0.9144 m (σ=0.862) and remained unchanged in 2007 (0.9144 m, σ=0) and 2019 (1.07 m, σ=0.647).

Dune area on Clearwater (Figure 43) and Indian Shores (Figure 44) Beaches was measured using spatial analysis tools in Google Earth Pro. Length of each dune was multiplied by its width, and a total dune area was calculated for each beach. Overall importance of dunes to total beach area has increased since 1995 at both beaches. In 1995, total dune area at Clearwater beach was 4,203 m², 3% of the entire beach area. In 2007, the dune area increased to 6% of the entire beach (8,658 m²) and in 2019 increased to 11% (16,941 m²). Similarly, at Indian Shores Beach in 1995 total dune area was 11,835 m², 3% of the entire beach area. In 2007, the total dune area increased to 15% (54,943 m²) and again in 2019 to 21% (77,389 m²).

Using historical images and the spatial analysis tools in Google Earth Pro, total beach area (Figure 45) was measured at Fort Desoto North Beach by tracing a polygon around the beach for the years 1995, 2007, and 2019 and calculating the area (m²) inside. Land has decreased progressively over the years from 277,025 m² in 1995, 187,821 m² in 2007, to 124,311 m² in 2019. Total beach loss during the 24 year period was approximately 45%.

Bed tax revenue (Figure 46) is a surrogate of tourism activity on Pinellas County’s beaches. March and April generate the most monthly revenue, $95.7 million in March and $67.3 million in April, as Spring Break vacationers arrive and stay for several weeks. The second most lucrative months are June and July, with $57 million and $58 million generated, respectively. Those months host visiting families on Summer vacation as well as locals seeking entertainment and recreation during Memorial Day and the
Fourth of July holidays. By early Fall, tourism slows as students return to school and the weather becomes cooler. September, October, and November generate the lowest revenue at $32 million, $34 million, and $35 million, respectively. As winter approaches, revenue increases during December ($39 million) and January ($47 million) when tourists arrive seeking Florida’s weather and to vacation for the holidays. By the end of February, winter vacation season has peaked ($63.5 million generated) and Spring Break season begins.

Mean monthly *Karenia brevis* concentrations from September 2018- September 2019 (Figure 47) were calculated using data collected by the Florida Fish and Wildlife Conservation Commission’s Harmful Algal Bloom group at the Fish and Wildlife Research Institute in St. Petersburg. Samples were collected weekly at several Gulf of Mexico stations around the beaches of Pinellas County. Beginning in September of 2018, mean *K. brevis* concentrations began to rise in the Gulf waters surrounding Pinellas County, nearly 900,000 cells/L and above. The red tide outbreak peaked in late October and early November when mean concentrations of *K. brevis* reached over 2.5 million cells/L. Concentrations decreased rapidly by the end of November and continued to do so throughout December, when mean *K. brevis* concentrations were under 15,000 cells/L. Finally, by January 2019, *K. brevis* levels were undetectable in the Gulf surrounding Pinellas County and remained so for the rest of the year.

Data on fish kills associated with red tide (Figure 48) were provided by Pinellas County Solid Waste Services. Fish kill data were collected daily on red tide-affected beaches throughout the county from September 2018-November 2018. Monthly total masses (kg) represent the sum of daily fish carcass collections at Pinellas County beaches. As the red tide outbreak reached Pinellas County in September, dead fish began to litter the Gulf beaches and by the end of the month over 700,000 kg had been collected. By October, approximately 1.2 million kg of dead fish had been collected. Following the red tide peak in late October, November had the greatest amount of dead fish collected at approximately 1.7 million kg.
Mean monthly temperature (Figure 49) and total monthly precipitation (Figure 50) data in Pinellas County were provided by the National Oceanic and Atmospheric Administration’s National Environmental Satellite, Data, and Information Service. Mean monthly temperature and total monthly precipitation were recorded between September 2018 and September 2019 at a weather station near St. Petersburg-Clearwater International Airport, located midway between study sites. August and September were the warmest months, with mean monthly temperatures of approximately 29°C. January was the coolest month with a mean temperature of approximately 16°C. From January to April, mean monthly temperature did not exceed 25°C. By May, mean temperature increased to over 26°C and continued to rise throughout the Summer. July and August were the wettest months, with precipitation totaling approximately 30 cm. The driest month was November with precipitation totaling just over 3 cm. There was a brief rainy period in December 2018 during which the total precipitation reached approximately 19 cm, but by January cooler temperatures brought drier conditions and the precipitation level decreased to approximately 12 cm. Levels remained relatively low (under 10 cm) until June when the wet season began.
Table 1: Scientific and common names, residential status, and abbreviations.

<table>
<thead>
<tr>
<th>Order and Family</th>
<th>Scientific Name</th>
<th>Common Name</th>
<th>Status in Pinellas County</th>
<th>Abbreviation</th>
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<td>Charadriiformes- Scopacidae</td>
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Figure 2: Trends in mean numbers of birds by group, 1980s-present on Pinellas beaches. Data sourced from The National Audubon Society Christmas Bird Count Archives.

Figure 3: Mean shorebird numbers in Pinellas County, 1980-2018. Data sourced from the National Audubon Society’s Christmas Bird Count Archives.
Figure 4: Mean gull numbers in Pinellas County, 1980-2018. Data sourced from the National Audubon Society’s Christmas Bird Count Archives.

Figure 5: Mean winter tern numbers in Pinellas County, 1980-2018. Data sourced from the National Audubon Society’s Christmas Bird Count Archives.
Figure 6: Mean wader numbers in Pinellas County, 1980-2018. Data sourced from the National Audubon Society’s Christmas Bird Count Archives.

Figure 7: Mean pelican and cormorant numbers in Pinellas County, 1980-2018. Data sourced from the National Audubon Society’s Christmas Bird Count Archives.
Figure 8: Mean corvid (fish crow) numbers in Pinellas County, 1980-2018. Data sourced from the Nation Audubon Society’s Christmas Bird Count Archives.

Figure 9: Mean year-round resident birds on Pinellas beaches, 1980s-present. Data sourced from The National Audubon Society Christmas Bird Count Archives.
Figure 10: Mean migratory birds on Pinellas beaches, 1980s-present. Data sourced from The National Audubon Society Christmas Bird Count Archives.

Figure 11: Mean number of individual birds by Feeding Guild. Data sourced from the National Audubon Society Christmas Bird Count Archives and Cornell University All About Birds Database.
Figure 12: Species Richness at Ft. Desoto North Beach, 2018-2019.

Figure 13: Ft. Desoto North Beach species richness of bird groups, 2018-2019.
Figure 14: Species richness at Indian Shores Beach, 2018-2019.

Figure 15: Indian Shores Beach species richness of bird groups, 2018-2019.
Figure 16: Species richness at Clearwater Beach, 2018-2019.

Figure 17: Clearwater Beach species richness of bird groups, 2018-2019.
Figure 18: Mean monthly bird abundance at Ft. Desoto North Beach, 2018-2019.

Figure 19: Mean monthly bird abundance at Indian Shores Beach, 2018-2019.
Figure 20: Mean monthly bird abundance at Clearwater Beach, 2018-2019.

Table 2: Summary of Kruskal-Wallis tests performed on richness and abundance. The annual means are displayed in the upper rows. The letters in the lower rows denote significant differences in distributions between sites.

<table>
<thead>
<tr>
<th></th>
<th>Clearwater Beach</th>
<th>Indian Shores Beach</th>
<th>Ft. Desoto North Beach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Species Richness</td>
<td>11</td>
<td>15</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bird Abundance</td>
<td>1049</td>
<td>2372</td>
<td>1109</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>B, C</td>
<td>D</td>
</tr>
</tbody>
</table>
Figure 21: Mean abundance of bird families at Ft. Desoto North Beach, 2018-2019.
Figure 22: Mean abundance of bird families at Indian Shores Beach, 2018-2019.
Figure 23: Mean abundance of bird families at Clearwater Beach, 2018-2019.
Table 3: Summary of Kruskal-Wallis tests performed on bird families. The annual means of each family are displayed in the upper rows. The letters in the lower rows denote significant differences in distributions between sites.

<table>
<thead>
<tr>
<th>Family/Sub-Family</th>
<th>Clearwater Beach</th>
<th>Indian Shores Beach</th>
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</thead>
<tbody>
<tr>
<td>Scolopacidae</td>
<td>51</td>
<td>361</td>
<td>130</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>B</td>
<td></td>
</tr>
<tr>
<td>Charadriidae</td>
<td>0</td>
<td>57</td>
<td>49</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Haematopodidae</td>
<td>0</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>B</td>
<td></td>
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<tr>
<td>Laridae</td>
<td>505</td>
<td>779</td>
<td>380</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>A</td>
</tr>
<tr>
<td>Sternae</td>
<td>399</td>
<td>725</td>
<td>445</td>
</tr>
<tr>
<td>Rynchopidae</td>
<td>0</td>
<td>468</td>
<td>145</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ardeidae</td>
<td>2</td>
<td>16</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pelecanidae</td>
<td>74</td>
<td>96</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>A</td>
</tr>
<tr>
<td>Phalacrocoracidae</td>
<td>26</td>
<td>27</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>A</td>
</tr>
<tr>
<td>Corvidae</td>
<td>79</td>
<td>38</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>B</td>
<td></td>
</tr>
</tbody>
</table>
Figure 24: Species abundance at Ft. Desoto North Beach 2018-2019.
Figure 25: Species abundance at Indian Shores Beach, 2018-2019.
Figure 26: Species abundance at Clearwater Beach, 2018-2019.
Table 4: Summary of Kruskal-Wallis tests performed on dominant species. The annual means of each family are displayed in the upper rows. The letters in the lower rows denote significant differences in distributions between sites.

<table>
<thead>
<tr>
<th>Species</th>
<th>Clearwater Beach</th>
<th>Indian Shores Beach</th>
<th>Ft. Desoto North Beach</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Kuddy Turnstone</strong></td>
<td>11</td>
<td>30</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>B</td>
<td></td>
</tr>
<tr>
<td><strong>Sanderling</strong></td>
<td>35</td>
<td>245</td>
<td>47</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>B, C</td>
<td>D</td>
</tr>
<tr>
<td><strong>Willet</strong></td>
<td>6</td>
<td>44</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Black Bellied Plover</strong></td>
<td>0</td>
<td>54</td>
<td>41</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Semipalmated Plover</strong></td>
<td>0</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Wilson’s Plover</strong></td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>American Oystercatcher</strong></td>
<td>0</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Laughing Gull</strong></td>
<td>465</td>
<td>739</td>
<td>365</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Ring Billed Gull</strong></td>
<td>38</td>
<td>35</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Forster’s Tern</strong></td>
<td>20</td>
<td>57</td>
<td>93</td>
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<td></td>
<td>A</td>
<td>B</td>
<td></td>
</tr>
<tr>
<td><strong>Royal Tern</strong></td>
<td>209</td>
<td>362</td>
<td>131</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>B</td>
<td></td>
</tr>
<tr>
<td><strong>Sandwich Tern</strong></td>
<td>171</td>
<td>307</td>
<td>221</td>
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<tr>
<td></td>
<td>A</td>
<td>B</td>
<td></td>
</tr>
<tr>
<td><strong>Black Skimmer</strong></td>
<td>0</td>
<td>468</td>
<td>145</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Brown Pelican</strong></td>
<td>74</td>
<td>96</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Double Crested Cormorant</strong></td>
<td>26</td>
<td>27</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Fish Crow</strong></td>
<td>79</td>
<td>38</td>
<td>19</td>
</tr>
<tr>
<td></td>
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<td>B</td>
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</tr>
</tbody>
</table>
Table 5: Feeding guilds at Clearwater, Indian Shores, and Ft. Desoto North Beaches.

<table>
<thead>
<tr>
<th>Feeding Guild</th>
<th>Guild Members</th>
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</thead>
<tbody>
<tr>
<td>Ground Foragers and Probers</td>
<td>Shorebirds, Gulls, and Crows</td>
</tr>
<tr>
<td>Aerial Divers</td>
<td>Terns and Pelicans</td>
</tr>
<tr>
<td>Surface Divers</td>
<td>Cormorants</td>
</tr>
<tr>
<td>Stalkers</td>
<td>Waders</td>
</tr>
<tr>
<td>Aerial Foragers</td>
<td>Skimmers</td>
</tr>
</tbody>
</table>

Figure 27: Monthly mean abundances of birds by feeding guild, 2018-2019.
Table 6: Summary of Kruskal-Wallis tests performed on feeding guilds. The annual means of individuals in each feeding guild are displayed in the upper rows. The letters in the lower rows denote significant differences in distribution between sites.

<table>
<thead>
<tr>
<th>Feeding Guild</th>
<th>Clearwater Beach</th>
<th>Indian Shores Beach</th>
<th>Ft. Desoto North Beach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground Foragers and Probers</td>
<td>636</td>
<td>1299</td>
<td>586</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>B</td>
<td></td>
</tr>
<tr>
<td>Aerial Divers</td>
<td>473</td>
<td>682</td>
<td>462</td>
</tr>
<tr>
<td>Surface Divers</td>
<td>26</td>
<td>27</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>A</td>
</tr>
<tr>
<td>Stalkers</td>
<td>2</td>
<td>16</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aerial Foragers</td>
<td>0</td>
<td>468</td>
<td>145</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 28: Monthly bird family abundances and *Karenia brevis* concentrations at Fort Desoto North Beach, September 2018-September 2019.
Figure 29: Monthly bird family abundances and *Karenia brevis* concentrations at Indian Shores Beach, September 2018-September 2019.
Figure 30: Monthly bird family abundances and *Karenia brevis* concentrations at Clearwater Beach, September 2018-September 2019.
Figure 31: Monthly bird family abundances and bed tax revenue on Fort Desoto North Beach, September 2018-September 2019.
Figure 32: Monthly bird family abundances and bed tax revenue on Indian Shores Beach, September 2018-September 2019.
Figure 33: Monthly bird family abundances and bed tax revenue on Clearwater Beach, September 2018-September 2019.
Figure 34: Monthly bird family abundances and mean temperature at Fort Desoto North Beach, September 2018-September 2019.
Figure 35: Monthly bird family abundances and mean temperature at Indian Shores Beach, September 2018-September 2019.
Figure 36: Monthly bird family abundances and mean temperature at Clearwater Beach, September 2018-September 2019.
Figure 37: Mean dune width on Clearwater Beach in 1995, 2007, and 2019. Data from Google Earth Pro. Width is measured perpendicular to shoreline.

Figure 38: Mean dune width on Indian Shores Beach in 1995, 2007, and 2019. Data from Google Earth Pro. Width is measured perpendicular to shoreline.
Figure 39: Clearwater Beach mean beach width for 1995, 2007, and 2019. Data from Google Earth Pro.

Figure 40: Indian Shores mean beach width for 1995, 2007, and 2019. Data from Google Earth Pro.
Figure 41: Clearwater Beach mean elevation for 1995, 2007, and 2019. Elevation was calculated using the elevations at 25 m and 50 m along a transect running perpendicular to the shore. Data from Google Earth Pro.

Figure 42: Indian Shores Beach mean elevation for 1995, 2007, and 2019. Elevation was calculated using the elevations at 25 m and 50 m along a transect running perpendicular to the shore. Data from Google Earth Pro.
Figure 43: Percent of total beach area comprised of dunes for 1995-2019 at Clearwater Beach. Data from Google Earth Pro.

Figure 44: Percent of total beach area comprised of dunes for 1995-2019 at Indian Shores Beach. Data from Google Earth Pro.
Figure 45: Fort Desoto North Beach total area from years 1995, 2007, and 2019. Data from Google Earth Pro.

Figure 46: Pinellas County bed tax revenue Sept 2018-Sept 2019. Data from Visit St. Pete-Clearwater Industry Partner Site.
Figure 47: Mean *K. brevis* concentrations surrounding Pinellas County’s Gulf Coast. Data from FWC, FWRI HAB Database.

Figure 48: Fish kill total mass in Pinellas County during the red tide outbreak period. Data from Pinellas County Solid Waste Services.
Figure 49: Pinellas County Mean Temperatures, Sept 2018-Sept 2019. Data from NOAA; National Environmental Satellite, Data, and Information Service.

Figure 50: Pinellas County Total Precipitation Levels, September 2018-September 2019. Data from NOAA; National Environmental, Satellite, Data, and Information Service.
Chapter Four: Discussion

The current study examined shorebird abundance and seasonality at three beaches representing a gradient of development and disturbance at three Pinellas County beaches. Distribution patterns of richness and abundance were then related to long term changes in their environment including beach width, beach elevation, dune width, dune area, and land loss (at Fort Desoto North Beach). The opportunity to examine bird distribution in response to two potentially disastrous environmental events was made possible due to a severe red tide outbreak and a category five hurricane that took place during the study period. Seasonal distribution was also related to the seasonal abundance of human activity on Pinellas beaches, which was represented by Pinellas County bed tax revenue.

Birds were classified as migratory (Winter) or resident (year-round) and sub-classified further by family and feeding guild. Bird families examined in the study included sandpipers (Scolopacidae), plovers (Charadriidae), oystercatchers (Haematopodidae), gulls (Laridae), terns (Sterninae), skimmers (Rynchopidae), pelicans (Pelicanidae), cormorants (Phalacrocoracidae), waders (Ardeidae), and crows (Corvidae). Feeding guild classifications were organized by the mechanism in which birds feed, including ground foragers and probers (sandpipers, plovers, oystercatchers, gulls and crows), aerial divers (pelicans and terns), surface divers (cormorants), stalkers (waders), and aerial foragers (skimmers).

Development and Disturbance in Pinellas County

The dynamic and nutrient rich coastal habitats of Pinellas County’s Gulf coast are ideal for hosting migratory and resident shorebirds. Barrier islands, dunes, and intertidal zones provide space and sustenance for migratory species to rest and refuel after long distance flights, as well as refugia for resident breeding species to rear offspring (Sprandel et al. 2000). Migratory shorebirds rely on stopover sites, such as the beaches of the Pinellas Gulf coast, for food and rest before continuing on their journey.
These sites must not only be of suitable size to host large groups of migrants, but must also be of appropriate quality to support their caloric needs. Their survival and reproductive success depend on their ability to stage at appropriate stopover sites (Burger and Niles 1997).

The condition of stopover habitats may be impacted by various factors, including human disturbance and development (Mengak et al. 2019). In densely developed areas where human disturbance is high, birds can be excluded from prime foraging habitat and may have to expend more energy fleeing from perceived danger than feeding or resting (Schlacher et al. 2013). Human disturbance at stopover sites has been identified by the Atlantic Flyway Shorebird Initiative as one of four main anthropogenic threats to migrating shorebirds (Mengak et al. 2019).

Since the 1950s, the Pinellas coastline has been severely altered by development and urbanization. Population expansion to the Gulf Beaches has eliminated or significantly transformed the structure of the coastline and adjacent habitats where shorebirds frequent due to high demand for beachfront property (Xian et al. 2005). In addition to real-estate and commercial development, shoreline modifications from beach renourishment projects have also changed the width, elevation, and depth of littoral zones on the Pinellas coast (Pinellas County 2020). As a result of development and urbanization, shorebirds have experienced loss and degradation of their habitat in many parts of the world (Zockler et al. 2003). Rising sea level as a result of climate change has furthermore reduced suitable shorebird habitat worldwide, threatening their survival and reproductive success (Galbraith et al. 2002). Due to extensive development and vulnerability to sea level rise, coastal habitats in Pinellas County were selected as study sites that provide a snapshot of a global shorebird conservation issue.

**Bird Distribution at Sites**

The least developed and least disturbed of the three sites examined in the study was Fort Desoto North Beach. This site had the highest species richness and second highest species abundance, as well as significantly fewer generalist species (gulls, crows, pelicans, and cormorants) than Clearwater Beach or
Indian Shores Beach. Fort Desoto North Beach was also the only site to host Wilson’s plovers, a species that is extremely sensitive to development (Hood and Dinsmore 2007) and in decline. Shorebird species richness, including migratory and year-round sandpiper and plover species, was highest at this site. The relatively pristine and undisturbed beach allowed for many species to stage during peak migration times in Fall and Spring. However, land loss from natural forces such as storms and erosion has reduced available habitat at Fort Desoto North Beach over the past 25 years by 45%. While habitat degradation from development and disturbance is not a major threat at this site, gradual loss of beach and intertidal zone from natural processes may affect bird distribution in the future. In addition to development, many habitats across the globe that were once suitable for migratory shorebirds have been inundated by water from rising seas or eroded away by storms, further threatening their survival (Galbraith et al. 2002). The small island that constitutes Fort Desoto North Beach will eventually disappear as a result of erosion or inundation, removing one of the few undisturbed habitats in Pinellas County for migrant shorebirds.

In contrast to Fort Desoto North Beach, Clearwater Beach, the most densely developed and disturbed site, had significantly lower species richness and abundance than the other two sites as well as a high abundance of generalists. At no time during the study period were skimmers, plovers, or oystercatchers observed on Clearwater Beach. Human activity at this site was nearly constant, both on the shore and in the water. In order to add green space to this otherwise completely modified beach, the city has created dune habitat for wildlife and allowed the man-made dunes to expand and grow vegetation over time. Despite the provisions by the city and the expansion of beach and dunes since 1995, bird distribution is significantly lower at Clearwater Beach than at the other two sites, suggesting that the constant disturbance deters them from using the beach as a stopover habitat (Schlacher et al. 2013). Generalist species, such as crows, are most abundant in areas of high human activity, where they can feed on scraps and refuse generated by tourists and fisherpeople (Walker and Marzluff 2015). The high abundance of generalists at Clearwater Beach not only indicate high levels of human activity at the site, but also the lack of suitable and appropriate space for shorebirds. Generalist species tend dominate in
areas with man-made or replicated habitats because specialist species are not supported, leading to low species richness and diversity (Atkinson 2003). The natural dynamic processes of dunes are extremely difficult to replicate, and the added human disturbance at Clearwater Beach further deters shorebirds from utilizing the habitat.

Bird distribution at Indian Shores Beach was also reflective of the level of development and disturbance throughout the year. Species richness and abundance were an intermediate of the other two sites, as this beach receives moderate levels of disturbance and is moderately developed. While neither richness nor abundance were significantly high or low, Indian Shores Beach did host all represented bird families throughout the year as well as a breeding colony of black skimmers during Summer. Migratory shorebirds were highly abundant during Fall and Spring migration, similar to what was seen at Fort Desoto North Beach. While species richness of shorebirds was not as high as what was observed at Fort Desoto North Beach, species abundance was much higher. Despite moderate development of the coast with small resorts, luxury homes, and cottages, Indian Shores Beach provides approximately 4 km of beachfront and intertidal habitat for both migrant and resident birds. Migratory shorebirds are supported nutritionally by the energetic littoral zone as well as wide areas of open beach for staging with moderate disturbance (Burger et al. 1997). Breeding species, such as skimmers, were allowed to colonize on the beach and use the plentiful dune habitat to safely hide chicks away from predators. As with Clearwater Beach, the dunes on Indian Shores Beach have increased in width and area since 1995. However, dune habitats at this site are natural and protected from human disturbance. By allowing Indian Shores Beach to retain some degree of natural habitat despite a moderate level of disturbance, it serves as an important site for hosting migratory shorebirds in need of rest and sustenance as well breeding species requiring space and refugia to raise their young.

*Environmental Parameters: Short Term Events*

From September-November 2018, a rapid increase in *Karenia brevis* concentration offshore of Pinellas County led to a severe outbreak of red tide. The large quantities of dead fish produced by the red
tide outbreak attracted thousands of gulls and hundreds of other carrion-eating birds such as crows and plovers. When concentrations of *K. brevis* decreased and removal of dead fish was completed, there was no attractant for carrion-eating species, and their abundance decreased. While the abundances of some bird families did increase during the outbreak, daily variation in bird abundance was too high to consider any statistical significance. One factor that may contribute to the high variation in daily bird abundance is fish kill clean-up efforts at the three sites. The removal of dead fish at Clearwater Beach was extremely diligent; A tractor pulling a waste-collecting device was driven along the shoreline throughout the day, removing dead fish immediately after it had washed ashore. Fish kill removal at Fort Desoto North Beach was mostly accomplished by park personnel, and fish kill was not allowed to accumulate in large amounts for a long period of time. However, at Indian Shores Beach, dead fish had been allowed to accumulate for several days to weeks before major clean-up efforts were made. Cleaning occurred during the night while beach visitors were not present. Despite nighttime attempts to clean the mess, by sunrise large amounts of fish kill had washed ashore again and would not be addressed for another several days (personal observation).

While shorebirds will opportunistically forage on carrion (Burger and Gochfeld 1980), fish kill contaminated with brevetoxins can potentially be fatal for them when consumed over an extended period (van Deventer et al. 2011). Several local bird rescue and rehabilitation facilities responded to reports of sick shorebirds showing symptoms of brevetoxin poisoning, including lethargy, weight loss, and ataxia. One bird rescue group (Birds in Helping Hands) collected several dozen individuals including ruddy turnstones and red knots displaying signs of illness during the red tide period from October-November 2018, and most were dead upon arrival. During the outbreak period, many individuals were observed feeding on the livers of dead fish that had washed ashore. Brevetoxins are strongly concentrated in liver tissues of fish that have succumbed to poisoning (Naar et al. 2007). Following an outbreak of red tide in Sarasota County during Fall 2005, deceased shorebirds found on local beaches were collected for necropsy. High concentrations of brevetoxins were found in their liver tissues, suggesting brevetoxin
exposure is a risk factor for shorebird mortality (van Deventer et al. 2011). The 2018 red tide event in Pinellas County also occurred in the Fall, which is when shorebirds arrive in large numbers from their Arctic breeding grounds. Because migratory shorebirds are attracted to and will opportunistically eat carrion (Burger and Gochfeld 1980), future red tide outbreaks offshore of Pinellas County that overlap with Fall migration could potentially lead to massive die offs of shorebirds that consume fish kill.

Hurricane Michael made landfall in the Florida Panhandle near Tyndall Air Force Base with winds estimated at 140 knots, making it a category 5 hurricane (Beven II et al. 2019). While the eye of the storm was approximately 520 km NW of Pinellas County, heavy rain, wind, and storm surge did impact the Gulf coast. A weather station near St. Petersburg- Clearwater International Airport reported wind gusts of 34 knots and approximately 3 cm of rainfall. The National Ocean Service reported storm surge of over 1 meter and an estimated inundation over 1 meter at Clearwater Beach (Beven II et al. 2019).

Evidence of minor storm surge was observed at all 3 sites, and Ft. Desoto North Beach had major damage to vegetated areas on the beach within the bird sanctuary. There did not appear to be any significant increase or decrease in abundance of bird families, species, or feeding guilds in response to precipitation, suggesting Hurricane Michael did not significantly impact Pinellas County’s shorebird population.

Human activity at the sites, as indicated by Pinellas County bed tax revenue, was highest during March and April and second highest in June and July. While not statistically significant due to daily variations in abundance, generalists such as gulls, crows, pelicans, and cormorants increased in abundance during periods of increased human presence on the beaches. Food scraps, garbage, discarded bait, and handouts from fisherpeople attract these species to the beach in search of an easy meal (Walker and Marzluff 2015). Tourism peaks in Pinellas County during Spring Break and Summer Holiday seasons. During March and April, shorebirds prepare for Spring migration by sleeping and consuming as much as possible. The intense physical exertion of long-distance flight requires shorebirds to be in peak physical condition before they depart to breeding grounds (Burger et al. 1997). Because shorebirds require undisturbed rest and foraging to prepare their bodies for migration, increased tourism to Pinellas
Beaches during Spring could potentially harm their fitness. Increased human activity on the beach from Spring Break vacationers may disturb and frighten resting groups of shorebirds, depleting their energy reserves (Smit and Visser 1993). Breeding species are also at risk of disturbance from increased human activity on the beach. Spring Break season in March and April partially overlaps with the skimmer courtship period (Erwin 1977). During this time, skimmers must colonize and select a suitable nesting location. Too much disturbance can spook them and cause them to abandon established breeding sites and stop reproductive effort (Carney and Sydeman 1999). Additionally, Summer tourism activity in Pinellas County peaks during June and July, when skimmer chicks are mobile but not flight capable. Increased human disturbance on the beach near nesting colonies can cause adult birds to physically harm or abandon their chicks (Carney and Sydeman 1999), and chicks are at risk of becoming trampled by pedestrians. Another consequence of increased human activity near nesting sites is increased predation. At Indian Shores Beach, fish crow abundance increased during Summer. Fish crows that were attracted to increased human activity also preyed on nestling skimmers and eggs, which is a common occurrence on Pinellas beaches (Forys et al. 2015).

**Environmental Parameters: Long Term Events**

In order to understand the impact of long-term sea level rise and development at the 3 sites, mean dune width, mean beach width, and mean dune area of Indian Shores and Clearwater Beaches were analyzed for changes using satellite data collected between 1995-2019. Due to the small size of Fort Desoto North Beach and its lack of dunes, changes in total beach area from 1995-2019 were examined using satellite data. Beach habitats on Indian Shores and Clearwater Beaches have been enhanced by dune construction and beach renourishment since 1995. Dunes and beach width at both sites have increased in size and the percentage of dune habitat has steadily increased. At Fort Desoto North Beach, however, beach habitat has decreased since 1995 as a result of natural forces such as erosion.
Despite increased dune width, beach width, and dune area on Clearwater Beach, overall species richness and bird abundance were significantly lower there than at Indian Shores Beach or Ft. Desoto North Beach. Clearwater Beach and Indian Shores Beach have similar wide, high energy beach fronts that allow for a dynamic littoral zone which may attract foraging shorebirds. However, unlike what was seen at Indian Shores Beach, shorebirds were not highly abundant at Clearwater Beach. Specialist birds, like oystercatchers, skimmers, and plovers, were not attracted to the site despite efforts to provide natural habitat for wildlife over time including beach renourishment and rules to protect dunes. While dune habitat and open beach are readily provided for wildlife use, the extremely elevated human disturbance at Clearwater Beach is a bird deterrent. In contrast, Fort Desoto North Beach, least developed site, was highest in species richness, hosted high abundances of specialist species, and had low abundances of generalists. While the site has been allowed to retain its natural features and attracts both migratory and breeding species, usable beach habitat has decreased by 45% since 1995. Erosion from storms have worn away and reduced beachfront for shorebirds to stage and forage, which may force them to locate more suitable habitat in the future. For species using Pinellas County as a stopover site, locating undisturbed beach and intertidal habitats may become increasingly difficult. As undeveloped coastline in Pinellas County is very scarce, species that relied on Fort Desoto North Beach for their Winter and breeding habitat may be subjected to decreased fitness and lowered reproductive success attempting to utilize less suitable habitats (Smit and Visser 1993)(Carney and Sydeman 1999).

**Future Implications and Global Conservation Issues**

Population growth in Pinellas County is projected to increase beyond 1 million people (PCHB 2008), which will lead to further development of the coast and intertidal habitats where shorebirds stopover and breed. Shorebirds are under continuous threat of habitat loss worldwide. Changes in habitat quality and accessibility at both migratory stopover sites around the globe and breeding grounds due to development, urbanization, and sea level rise jeopardize their long-term survival and reproduction. As seen in other examples from around the globe, shorebirds relying on Pinellas County for wintering and
breeding grounds are under serious threat of habitat loss and degradation from human-induced changes in their environment.

One example of critical loss of important Winter habitat is the degradation of tidal flats along the Yellow Sea in China and South Korea. Shorebird populations that use this area for staging on the East Asian-Australasian Flyway are currently collapsing (Murray and Fuller 2015). Long term surveying of migratory shorebirds at the Flyway terminus in Eastern Australia has revealed a 73% decline in numbers between 1983 and 2006 (Nebel et al. 2008). Tidal flats of the Yellow Sea and throughout East Asia are vital locations for millions of migratory shorebirds to feed and rest while en route to and from the Arctic and sub-Arctic (Murray and Fuller 2015). However, analysis of satellite data has shown that nearly 70% of these critical habitats have been lost due to urban, industrial, and agricultural land reclamation (Murray et al. 2014). The South Korean government has recognized the need to restore and protect these important tidal flats and has applied to UNESCO to make areas along Gosmo Bay, Yeoja Bay, Hamhae Bay, and the Sinan Archipelagoes a World Heritage Site. As of 2019, China has halted further land reclamation of the Yellow Sea coast and has begun the process of nominating Chinese tidal flats for World Heritage Site consideration.

Reduction of habitat quality from development related factors can also pose a severe problem for shorebirds already imperiled by habitat loss. One recent concern regarding global shorebird conservation is habitat degradation by microplastics pollution. Large amounts of microplastics were found in feces of shorebird populations that overwinter in Western European and West African wetlands located near heavily developed areas (Lourenco et al. 2017). Additionally, heavy metals such as arsenic and selenium from industrial sources can enter the food web and affect shorebird fitness. In parts of South Korea and the Southern Great Plains of the United States, shorebirds using wetland habitats adjacent to urbanized areas had detectable levels of heavy metals in their feathers, blood, and tissues (Kim and Koo 2007), (Ashbaugh et al. 2018). Both microplastics and heavy metal contaminants can enter the food web and be concentrated in tissues of invertebrate prey consumed by shorebirds, putting their health and survival at
risk. While policies may be established to protect critical shorebird habitats around the world from further development, shorebirds are still at risk from secondary impacts of urban, agricultural, and industrial land use, all contributing to watershed contamination.

Creation of replacement habitats for natural ones that have been lost or damaged due to development or sea level rise is a common solution in many parts of the world, including Pinellas County, Florida. While restoration and reconstruction of terrestrial habitats are well understood, intertidal habitats such as the ones used by migratory and breeding shorebirds can be more difficult to restore because their topographical and ecological complexities must be taken into consideration (Atkinson 2003). Many species living in these habitats have specific requirements for survival including connections to other terrestrial and marine habitats. This makes intertidal habitats, like sandy beaches and mudflats, difficult to replicate. Another quality of intertidal habitats that is difficult to mimic is their ability to exist in dynamic coastal settings and adapt to changing tide levels, salinities, and long-term mechanical processes (Atkinson 2003). At many created or restored coastal wetlands and beaches, there exists reduced species diversity because the natural processes necessary to support a wide variety of flora and fauna cannot be replicated. As a result, generalist species dominate the area (Atkinson 2003), as was the case with Clearwater Beach with low species richness despite plentiful and large created dunes.

Potential impacts of climate change-- including sea level rise, flooding, and increased frequency and intensity of storms, have stimulated global efforts to protect coastal habitats from degradation and loss. In many countries, beach renourishment has been a viable solution to erosion and land loss from storms and rising sea levels. In Pinellas County, efforts to protect coastal habitats include periodic beach renourishment by dredge-and-fill. While providing storm protection and creating additional beach space, renourishment can have negative implications for beach fauna, including shorebirds. Beach renourishment can bury established littoral zone habitats where shorebirds forage for invertebrate prey or reduce the density of prey where new sediment has been applied (Peterson and Bishop 2005). Studies of macroinvertebrate assemblages suggest that renourishment decreases species richness and density.
(Rakocinski et al. 1996). For migratory shorebirds requiring rest and sustenance, reduction in availability of prey as well as increased energy expenditure to locate prey may affect their fitness (Grippo et al. 2007). In addition to increasing sediment depth and altering littoral zone structure, heavy machinery used in the renourishment process can be a potential environmental disturbance. Frequent traffic on the beach from large vehicles and movement of dredge pipes can frighten shorebirds to the point of flushing them, further depleting their energy reserves. In early September 2018, a beach renourishment project was completed on Indian Shores Beach. Large groups of resting shorebirds, including red knots, sanderlings, and willets were observed flushing from heavy machinery and noise produced by the dredging process (personal observation). Frequent disturbance by vehicle activity in shorebird habitat can reduce their abundance in areas where they forage and stage (Tarr et al. 2010).

In conclusion, shorebirds in Pinellas County, Florida appear to be resilient in response to short term, potentially catastrophic changes in their environment such as an outbreak of red tide and indirect impacts from a category 5 hurricane. However, they exhibit significantly greater responses to long term changes in their environment, such as development. Globally, development is the greatest contributing factor to loss of critical shorebird habitat and their consequential decline. The lowered distribution of shorebirds at highly developed beaches in Pinellas County despite efforts to restore and recreate habitat reflect this trend.
References


