INVESTIGATION OF FACTORS INFLUENCING PIPING PLOVER DISTRIBUTION ALONG THE UPPER TEXAS COAST

by

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ABSTRACT

INVESTIGATION OF FACTORS INFLUENCING PIPING PLOVER DISTRIBUTION ALONG THE UPPER TEXAS COAST

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Nonbreeding Piping Plovers *Charadrius melodus* rely on coastal estuaries and ocean-fronting beaches for feeding and roosting; however, these same habitats have suffered historical losses and continue to be impacted and degraded through human encroachment and development. This is a concern as approximately 50% of the global population of Piping Plovers rely on the Texas shorelines for two-thirds of their annual life cycle. In this study, we conducted weekly beach surveys during the 2012-13 nonbreeding season along Follets Island and Galveston Island, two barrier islands with varying levels of recreation and development, to determine the abundance and distribution of nonbreeding Piping Plovers and identify anthropogenic and environmental factors most influencing their distribution. Factors investigated included: habitat parameters (e.g. size and proximity of bayside intertidal flats and benthic prey availability), recreational use (e.g., people, vehicle, and dog density), beach management practices (e.g., beach driving and raking), and intensity of housing development. We found that the combined influence of beach driving and the anthropogenic influences from development were the most important factors influencing the distribution of Piping Plovers along both islands, while the proximity to large areas of intertidal flats may be a contributing factor in site selection. Given the increasing rate of population growth and development along the Texas coastline, these results can be utilized to help guide future management to reduce disturbance to Piping Plovers and increase habitat quality and site use of important beach habitat.

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INTRODUCTION

Many shorebirds have life cycles that are tied strongly to open coastal habitats such as wetlands, estuaries, tide flats, and ocean-fronting beaches (Colwell 2010). Migrating and wintering shorebirds depend on these habitats in their nonbreeding ranges for feeding and roosting, allowing them to replenish food and energy reserves needed to complete lengthy migrations and survive inclement winter weather. These coastal habitats are being lost and degraded through increased human growth and development of coastal areas. Loss of these important migration and winter sites can have negative consequences for many shorebird populations. Nearly 50% of the world's shorebird populations are in decline due to habitat loss and other factors (Colwell 2010).

The Piping Plover[1] *Charadrius melodus* is an endangered shorebird species threatened by habitat loss resulting from shoreline development, beach maintenance practices, shoreline stabilization, inlet dredging, and other coastal development activities (U.S. Fish and Wildlife Service 2009b). Piping Plovers rely on shoreline habitats throughout their annual life cycle (Bock and Jones 2004). They nest on the shorelines of lakes, reservoirs, rivers, and coastal beaches in the Northern Great Plains, the Great Lakes, and along the Atlantic coast of North America during their April to August breeding season. They are found in their nonbreeding ranges from July through May when they migrate to stop-over and wintering areas along the south Atlantic, Gulf of Mexico, and Caribbean coastlines, where they spend up to two-thirds of their annual life

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[1] The term "Plover" is used in the text interchangeably with Piping Plover unless otherwise noted.

cycle (Haig and Oring 1985, Johnson and Baldassarre 1988, Haig and Plissner 1993, Noel et al. 2007).

Piping Plovers use a mosaic of shoreline habitats such as coastal beaches, bayside flats, and tidal inlets for feeding and roosting in their migration and wintering ranges (Nicholls and Baldassarre 1990, Cohen et al. 2008). Plovers move between these habitats during daily tidal cycles and exhibit seasonal trends in the use of particular coastal habitats. Over a single tidal cycle, Plovers will typically use ocean beaches during high tides for roosting exhibiting multiple behaviors (i.e. resting, standing, preening, alert), and move to bayside habitats during ebb and low tide for foraging when maximum aerial exposure of intertidal areas occurs (Zonick 2000, Cohen et al. 2008, Maddock et al. 2009, Newstead and Vale 2014). Seasonally, Plovers exhibit higher use of ocean beaches during fall and spring months, whereas sand flats adjacent to beaches or coastal inlets are utilized more during the winter (Haig and Oring 1985). Nicholls and Baldassarre (1990) also found tidal inlets provided important habitat, observing Piping Plovers at 72% of surveyed sites.

Members of the Plover family, Charadriidae, show similar spatial distribution patterns based on their behavior in the nonbreeding season. When feeding, Plovers generally distribute themselves in an even pattern on the beach and are often observed defending feeding territories on the beach. When roosting, Plovers generally flock together at roost sites, particularly in the winter to reduce the risk of predation, thereby distributing in a clumped pattern on the beach (Colwell 2010). This distribution pattern has been observed in Piping Plovers, who exhibit a high degree of site fidelity and occupy small home ranges (Drake et al. 2001, Cohen et al. 2008, Noel and Chandler

2008, Newstead and Vale 2014). Zonick (2000) observed intraspecific agonistic behaviors of wintering Piping Plovers defending feeding territories and an average spacing of 100 – 200 m between each Piping Plover on the beach. Noel and Chandler (2008) observed banded Piping Plovers >75% of the time on the same section of beach within a distance of 1 km – 4.5 km. Newstead and Vale (2014) detected radio-tagged Plovers in well-defined territories on sections of beach along the Texas coast. Other telemetry studies on wintering Piping Plovers reported mean home range size varying between 3.9 - 20.1 km^2 and a mean core area of 2.2 km^2 and 2.9 km^2 (Drake et al. 2001, Cohen et al. 2008).

Piping Plovers have been documented returning to the same sites the following winter. Reported between-year return rates range from 63% to 100% for banded Piping Plovers (Johnson and Baldassarre 1988, Noel and Chandler 2008, D. Newstead, Coastal Bend Bays & Estuaries Program, unpublished data).

Piping Plovers were listed as a threatened and endangered species under the Endangered Species Act in 1986 in their wintering and Great Lakes breeding range, respectively, due to unregulated overhunting in the early 1900's, and human encroachment into and extirpation from their breeding range (Bent 1929, U.S. Fish and Wildlife Service 1985). Since receiving federal protection, Piping Plover populations continue to be challenged with anthropogenic threats in both their breeding and wintering ranges. The two most significant threats to nonbreeding Piping Plovers are habitat loss and degradation, and increased disturbance by people and their pets (e.g., dogs) (U.S. Fish and Wildlife Service 2009b). Piping Plovers, both breeding and nonbreeding, have been observed spending significantly less time foraging when humans were present (Burger 1994, Elliott 1996).

The quality of critical migration and wintering habitats continue to decline due to shoreline development, artificial structures, inlet dredging, and beach maintenance and nourishment (U.S. Fish and Wildlife Service 2009b). Protection of these habitats, along with critical migratory stop-over and wintering sites is vital for the recovery of Piping Plovers, especially on the Texas coast. Through the International Piping Plover Census (IPPC) implemented the U.S. Fish and Wildlife Service (USFWS) in 1991, approximately 50% of the Piping Plover population have been observed wintering on the Texas coastline (Plissner and Haig 1997, Ferland and Haig 2002, Elliott-Smith et al. 2009, Elliott-Smith et al. 2015). The latest 2011 IPPC census estimated a wintering population of 3,973 Piping Plovers, with 54% of the population observed on the Texas coastline (Elliott-Smith et al. 2015).

Much of the habitat loss and degradation has occurred along Gulf beaches. The Texas Parks and Wildlife Department (TPWD) reported that the state has already lost 30% of wintering Plover habitat over the previous 20 years since the species listing (U.S. Fish and Wildlife Service 2009b). A 29-year shorebird study (1979 – 2007) on Mustang Island, TX reported a fivefold increase in mean number of people, nearly twice the mean number of vehicles on the beach, significant increases in development of condominiums and residential communities with direct beach access, and a 25% decrease in the occurrence of Piping Plovers (Foster et al. 2009).

Habitats used by nonbreeding Piping Plovers continue to be under intense pressure from the high concentration of people located along coastlines. Coastal areas are the fastest growing regions in the United States (Field et al. 2000). It is estimated that 53% of the United States human population lives in coastal areas and are predicted to increase nearly 25% by 2025 (Field et al. 2000). In Texas, the total human population is projected to grow 42% by 2050 with populations along the coast expected to increase 35% by 2025 (Field et al. 2000, Texas Water Development Board 2015). Tourism on Galveston Island, located approximately 50 miles from the fourth largest city in the United States – Houston – reached an all-time high in 2013 with 5.8 million visitors (Tourism Economics 2014).

With Galveston Island's close proximity to the sprawling Houston metropolitan area, available Plover habitat is at greater risk each year due to increasing numbers of local tourists and development of the beach and bayside areas for housing, vacation rentals, and associated tourism industries. These additional stressors will pose major challenges to the successful conservation of the Piping Plover since 54% of the winter population uses the Texas coastline for two-thirds of its life cycle (Elliott-Smith et al. 2015). Management of Piping Plovers at ecologically important sites in coastal areas has proved difficult as there is a continual conflict between concurrent management of public recreational access and ecosystem conservation (LeDee et al. 2010).

Recent research has provided information on habitat use and ecology of nonbreeding Piping Plovers (Nicholls and Baldassarre 1990, Drake et al. 2001, Cohen et al. 2008, LeDee et al. 2008), however few studies have been conducted on the distribution of Plovers along Gulf beaches and even less along the upper Texas coast (Zonick 2000, Arvin 2010, Newstead and Vale 2014). Furthermore, most nonbreeding studies of habitat use have occurred in areas that have lower densities of recreation and development where Plovers are expected to occur in higher densities. With the continued predicted human population growth and development in coastal areas, it is important to understand how Piping Plovers are distributed along Texas beaches and determine what anthropogenic factors may be affecting available habitat and habitat use. Studying a species abundance and distribution can help us understand factors influencing the species' site selection and help elucidate variables that influence habitat quality which can have direct consequences for individual survival and local population size (Colwell 2010).

STUDY OBJECTIVE AND HYPOTHESIS

The objectives of this research were to 1) characterize and document the seasonal abundance and distribution of Piping Plovers along Follets Island and Galveston Island, two barrier islands of varying levels of development and human use and 2) determine major human and natural factors influencing the distribution of this species. Specific tasks included 1) determining the spatiotemporal abundance and distribution of Piping Plovers along Follets Island and Galveston Island beaches; 2) identify concurrent anthropogenic use of shoreline areas including number of people, pets, and vehicles; 3) characterizing beach maintenance activity along Gulf beaches; 4) characterizing physical land-use and land-cover within the home range of Plovers; 5) evaluating prey abundance and physicochemical conditions and 6) developing statistical models that attempt to describe the variation in Plover occurrence based on multiple candidate variables that were measured. The a priori hypothesis was that seasonal Piping Plover abundance and distribution on the beach is affected by density of human activity (people, pets, and vehicles) and other anthropogenic factors such as degree of land development and beach management practices. This research was conducted to provide resource managers data and information on beach use and management practices that may threaten Piping Plovers, which will aid in species recovery efforts.

METHODS

Study Area

The study area included portions of Gulf of Mexico beach shoreline of Follets Island and Galveston Island, TX, two barrier islands separated by a natural tidal inlet named San Luis Pass (Figure 1). The survey area included the eastern 14.7 km shorelines of Follets Island and the western 21 km of Galveston Island. Both islands have varying levels of recreational activity, land development, and employ various types of beach management. Both areas have historically supported nonbreeding populations of Piping Plovers (Haig and Plissner 1993, White and Elliott 1998, Zonick 2000).

Follets Island

Follets Island is in Brazoria County, TX and is approximately 23 km long and varies in width from 0.3 to 2.0 km. The island is bounded on the northwest side by West Bay and Christmas Bay and on the southeast by the Gulf of Mexico (Figure 1). The neighboring bay systems have an average depth of 0.9 m and are separated by a network of uninhabited islands (National Oceanic and Atmospheric Administration 2016). Follets Island attracts recreational users who fish, hunt, and kayak the bay side and also camp,

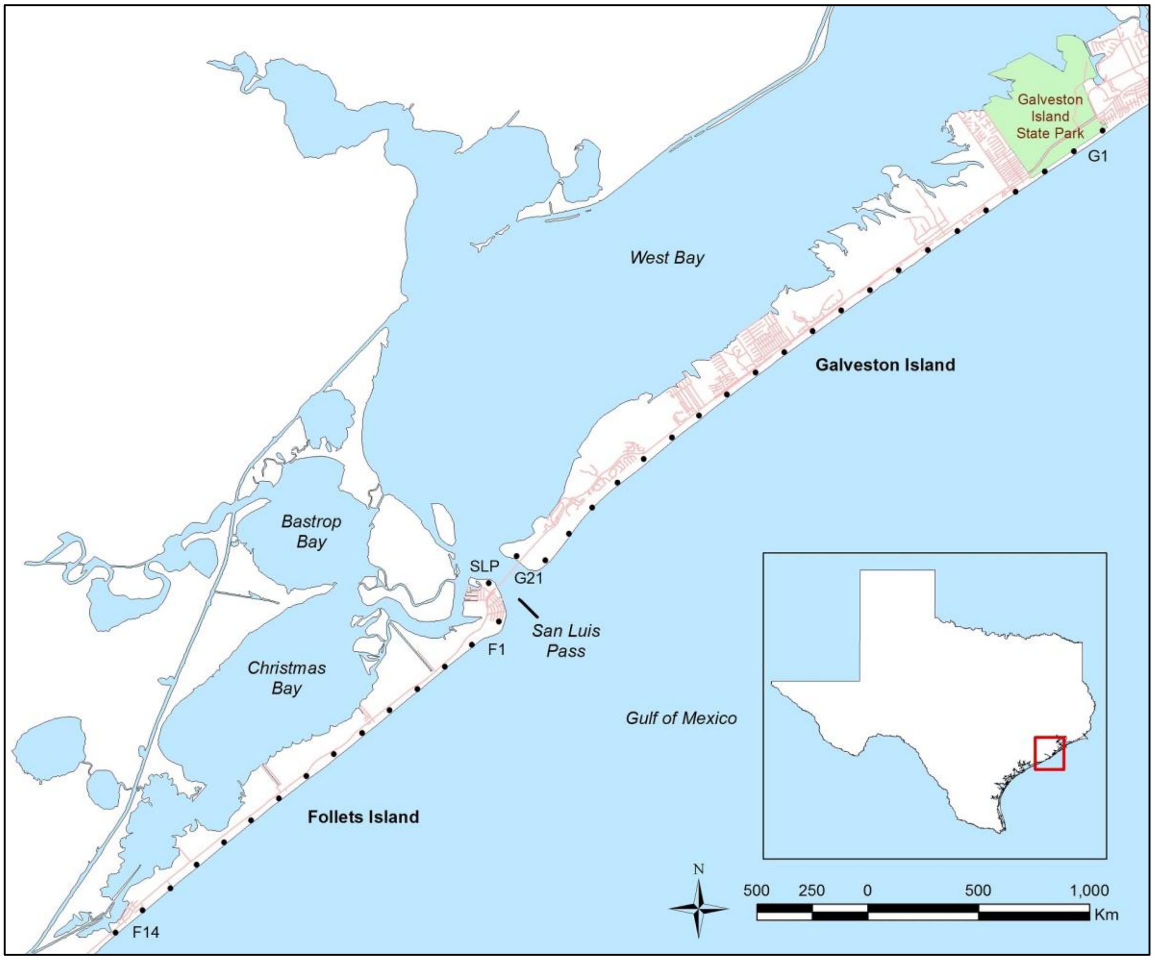


Figure 1. Study area of Galveston Island and Follets Island, Texas. Each survey transect labeled with a dot.

swim and fish on the Gulf beach side. A large proportion of Follets Island has little to no development, except at the extreme ends of the island. The southwestern 6 km of shoreline is classified as low to moderately developed and is located within the city limits of Surfside Beach, TX. Surfside has a resident population of 496 people and is located adjacent to Port Freeport. At the northeastern tip of the island is San Luis Pass County Park, a 6-hectare park situated on the inlet shoreline. Park amenities include both day-use and overnight facilities, a boat launch, beach and paved parking, and fish cleaning stations. Surrounding the park is Treasure Island, a small subdivision community with approximately 25 residents and a number of vacation homes along the beach and bay shoreline (Treasure Island Municipal Utility District 2015). Tourism data was not reported for Follets Island, however high levels of beach recreation are concentrated around Surfside Beach, with seasonal recreational peaks in activity occurring at San Luis Pass Park. The Follets Island survey site included the inlet shorelines of San Luis Pass County Park, and the Gulf shorelines of Treasure Island and southwest stopping 2 km before Surfside Beach city limits.

Galveston Island

Galveston Island is in Galveston County, TX and is approximately 47 km long and varies in width from 1 to 5 km before tapering towards San Luis Pass on the west. The island is bounded by West Bay to the northwest and the Gulf of Mexico to the southeast (Figure 1). West Bay has an average depth of 1.5 m and has minimal bayside habitat structures between the island and the mainland (National Oceanic and Atmospheric Administration 2016). The northeast tip of the island is along the Houston Ship Channel and site of the Port of Galveston which harbors many cruise ships, cargo ships, and natural resource exploration ships daily. The island has two incorporated cities which include Galveston, with a resident population of 47,762, and Jamaica Beach, a narrow 207-hectare city situated in the middle of the city of Galveston, with a resident population of 1,001. Galveston Island is approximately 50 miles from the Houston metropolitan area, and hosts millions of tourists each year, reaching an all-time high of 5.8 million visitors in 2013 (Tourism Economics 2014). Major attractions on Galveston Island include: large public beaches, hotels and resorts, shopping areas, restaurants, amusement rides, cruise ship terminals, and seasonal festivals and events.

The majority of development, recreational activity, and resident population is concentrated on the eastern half of Galveston Island, while the western half has alternating patches of undeveloped and developed beach and bay shorelines that consist mostly of weekend homes, vacation properties, and resorts. Galveston Island State Park is an 809-hectare park located on the western half of the island that extends from beach to bay. Park amenities include day-use and overnight facilities, beach recreation, kayaking trails, hiking trails, and fish cleaning stations. The Galveston Island survey site included the shorelines of Galveston Island State Park, Jamaica Beach, and the shoreline southwest to the San Luis Pass Inlet.

Beach Habitat

The Gulf beach shoreline consists of a mix of low to high continuous and discontinuous vegetated dunes terminating in narrow gently sloping sandy beaches which are normally exposed to low energy waves. Levels of freshly deposited shoreline wrack (i.e., organic material such as macroalgae) vary seasonally. High amounts of *Sargassum* spp. are sometimes deposited on the beach from May through August, while fresh wrack becomes infrequent in other months. The freshwater plant water hyacinth (*Eichhornia* spp.) is occasionally deposited on the beach after heavy rain events which results in high river flows.

The San Luis Pass inlet is a wide open sandy beach with shifting shorelines due to fluctuating sand deposits from strong currents and tides passing through the narrow 0.9 km wide inlet. Habitat directly behind the inlet consists of shallow intertidal flats mixed of sand and mud that become exposed from either wind induced or lunar tidal regimes. San Luis Pass is considered a critical habitat site for Piping Plovers (Unit TX-34) with an area of 110 ha that is comprised of approximately 7 km of Gulf and inlet shoreline, and 57% of intertidal flats inside the Pass (U.S. Fish and Wildlife Service 2009a).

Field Methods

Bird Surveys

The 14.7 km and 21 km Gulf beach shoreline of Follets Island and Galveston Island, respectively, were surveyed for Piping Plovers from 3 August 2012 through 25 May 2013 (*n* = 43 survey dates). Surveys were conducted in one kilometer linear transects arranged serially along each continuous survey route to capture Piping Plover and recreational use densities (Figures 1). Follets Island's survey route included one inlet transect and 14 continuous beach transects (*n* = 15). The inlet transect included 0.7 km of beach shoreline and interior lagoon at San Luis Pass County Park, transect name SLP. The 14 continuous beach transects started one km directly south of SLP at Treasure Island subdivision southwestward to the northeastern border of the town of Surfside Beach, transect names F1 – F14 respectively. Galveston Island's survey route consisted of 21 continuous beach transects between Galveston Island State Park (GISP) southwestward to the inlet beach shoreline of San Luis Pass, transect names G1 – G21 respectively (Figure 1). A longer survey route was chosen for Galveston Island to include the minimally developed shoreline within Galveston Island State Park. The bayside intertidal flats at San Luis Pass were excluded from the survey.

Follets Island and Galveston Island were surveyed once a week on the same day. The starting location (i.e. Follets or Galveston Island) and day of week (i.e. weekday or weekend) were alternated between weekly surveys to capture the effect of time of day and varying levels of human use on Piping Plover distribution on each island. Furthermore, surveys were conducted so the sun was behind the observer to reduce glare and improve detectability and identification of birds. To achieve this criteria with the moving sun, surveys were conducted in a southwesterly direction on the first island (starting transect G1 or SLP), and northeasterly on the second island (starting transect G21 or F14). All surveys began approximately 30 minutes after sunrise ($\bar{x}$ = 39.6 ± 4.37 SE) and encompassed all tide levels and under a variety of weather conditions, except during heavy rain or winds exceeding 30 mph which made it hard to see the birds. Survey length times ranged between 57 – 315 minutes ($\bar{x}$ = 156.8, SE = 10.7, n = 43) on Follets Island and 105 – 410 minutes ($\bar{x}$ = 225.3, SE = 11.0, n = 43) on Galveston Island, with a cumulative daily average of 451 minutes ± 21 SE to complete both site (i.e., island) surveys. An all-terrain vehicle (ATV) or 4x4 SUV was driven during the surveys, taking special precaution not to disturb feeding and roosting birds while staying off dune habitats.

Data collected for each Piping Plover observation included time, GPS coordinates, behavior of the bird when first observed (i.e., feeding or roosting), band/auxiliary marker information (when applicable), and percentage of beach covered by natural wrack (perpendicular from the water's edge). Plovers were given the same GPS coordinates if >1 Plover was observed within a 10 m radius. Distance and bearing of each Piping Plover from the observer was documented and later projected in GIS to estimate the exact location of the bird. Distance was measured with a Bushnell Legend 1200 Arc rangefinder with an accuracy of +/- 1 meter and a built in inclinometer which allows calculation of horizontal distance. The bearing was collected using a standard compass; magnetic declination corrections were made prior to data analysis. Behaviors were defined based on previous Piping Plover studies and shorebird ecology literature (Burger 1991, Colwell 2010). Behaviors were categorized into the following: feeding (i.e., searching, pecking, running, agonistic) and roosting (i.e., resting, preening, bathing).

Data collected for each transect included total counts of Piping Plover, humans, vehicles, and dogs (leashed and unleashed), beach management practices (e.g. driving, beach raking), beach width (dune or vegetation line to water's edge), and environmental parameters such as air temperature, wind speed and direction, and mean sea level (msl). Beach management variables were collected once at the beginning of the study and were fixed variables in the analysis. Air and wind data was obtained from meteorological station 526 at San Luis Pass and mean sea level readings were obtained from tide station 152 in Freeport, TX approximately 21 miles southwest of San Luis Pass (Texas Coastal Ocean Observation Network 2012). Tide data was not obtained from station 526 at San Luis Pass because the station was silted in through the entirety of this study.

Benthic Collection

Habitat quality and prey availability was assessed by collecting benthic and sediment core samples from areas with varying levels of Piping Plover and human use located within the aforementioned survey routes. Such areas were chosen to evaluate the influence that anthropogenic (e.g., degree of human/vehicle use, amount of beach maintenance) and biological (e.g., environmental conditions, benthic prey availability, etc.) factors have on Piping Plover distribution and abundance. Benthic sampling protocols were developed utilizing methods from several published resources on Piping Plover foraging behavior, wading birds and prey density, and beach benthic communities on Galveston Island (Engelhard and Withers 1997, Marks and Guillen 1999, Zonick 2000).

Benthic sampling was conducted monthly from October 2012 – May 2013, near the 20th day of each month. Sixteen sampling sites were established in a randomized block design and sampled during each event that met site criteria based on a randomized block design. Only eight sites were sampled in October and later doubled to gain more information across more sites (Table 1). Eight of the 16 sampling sites exhibited a combination of little or no Piping Plover use (0-1 birds) and human use (0-14.5 humans and/or 0-2.5 vehicles) on raked/unraked beaches. Eight sites exhibited high Piping Plover use (>1 birds/km) and use (>14.5 humans/km and/or >2.5 vehicles/km) on raked/unraked beaches. Site criteria were gathered using bird survey counts prior to October's benthic sampling and by determining beach maintenance regimes through contacts with local municipalities and site observation. The low and high boundaries were determined using the median level of Piping Plover, human, and vehicles observed

Table 1. Benthic sampling sites between October 2012 and May 2013. Sample sites were based on early fall Piping Plover use, human use, and beach management practices (beach raking). Transects starting with F = Follets Island, G = Galveston Island.

Site	Plover Use	Human/Vehicle Use	Beach Mgmt.	Transect	Benthic *n*	Substrate *n*
HHR-1	High	High	Raked	G10	7	3
HHR-2	High	High	Raked	F5	8	4
HHU-1	High	High	Unraked	G4	7	3
HHU-2	High	High	Unraked	F-SLP	7	3
HLR-1	High	Low	Raked	G7	7	3
HLR-2	High	Low	Raked	F1	8	4
HLU-1	High	Low	Unraked	G9	8	4
HLU-2	High	Low	Unraked	F2	7	3
LHR-1	Low	High	Raked	G13	7	3
LHR-2	Low	High	Raked	G14	8	4
LHU-1	Low	High	Unraked	G20	8	4
LHU-2	Low	High	Unraked	F12	7	3
LLR-1	Low	Low	Raked	G5	7	3
LLR-2	Low	Low	Raked	G19	8	4
LLU-1	Low	Low	Unraked	F4	7	3
LLU-2	Low	Low	Unraked	F9	8	4
HLU	High	Low	Unraked	G1	3	2

per transect. One additional benthic monitoring site, site name HLU, was sampled in October, February, and May to evaluate the relative influence of human disturbance, seasonality, physical conditions, and benthic prey availability on Piping Plover occurrence and abundance.

Three replicate benthic core samples, spaced 3 m apart, were collected at each sample site within the upper quartile of the active swash zone (Figure 2). Samples were collected near the upper end of the swash zone to coincide with the primary foraging zone of Piping Plovers (Zonick 2000). Benthic core samples were collected to a depth of 5 cm using a clear PVC core with an inner diameter of 0.1905 m. Samples were washed through a 500 μm bucket sieve and the remaining invertebrates were fixed with 70% ethanol and stained with Rose Bengal in the field. In the lab, each sample was sorted, identified to the lowest taxonomic level feasible, and counted. Empty bivalve and mollusk shells were not counted. Paired substrate samples were collected for sediment grain size analysis during the first and last sampling quarter ($n = 57$). Substrate samples were collected at a depth of 5 cm using a metal core with an inner diameter of 7 cm. Substrate samples were collected to the right of the middle benthic core sample, facing the Gulf (Figure 2). Sediment grain size analysis was conducted using an abbreviated method used to estimate “percent fines”, which is the amount of sediment that is classified as being silt or clay (Eaton 1994).

During each benthic collection environmental and habitat data were also collected including sample time, air temperature, wind speed and direction, tide level, beach width, natural wrack percentage, count of Piping Plover, humans, vehicles, and dogs within a 50 m radius of the sample location, and physicochemical water parameters (water

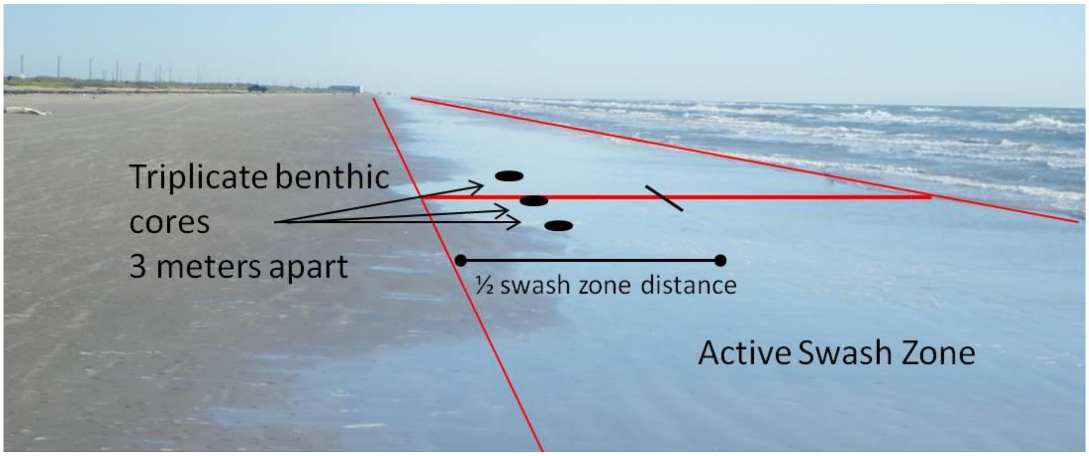


Figure 2. Benthic sampling design layout showing the position of the three replicate benthic core samples within the upper quartile of the swash zone (not to scale). Paired substrate samples were collected to the right of the middle benthic core sample, facing the Gulf.

temperature and salinity) using a YSI sonde.

Data Analysis

Piping Plover Abundance

Piping Plover site abundance was analyzed to compare mean monthly and seasonal differences between and within survey islands. Mean site abundance was calculated by dividing the total count of Piping Plovers recorded per island by the number of surveys conducted each season and study period. To compare site abundance, Plover densities were calculated by dividing total survey counts by the length of beach surveyed per island. Site abundance was evaluated by seasons and partitioned based on criteria established by Noel et al. (2007): fall – August through October; winter – November through February; spring – March through May. Birds observed in the fall and spring months were classified as migrants, and birds present between November and February were classified as wintering birds. Abundance data was analyzed using the Minitab ™ statistical software, version 17 (Minitab, Inc., State College, PA). Scatterplot, histograms and bar charts were generated to visually examine temporal and spatial trends in Plover densities. Non-parametric tests (e.g. Mann-Whitney) were used for comparison analysis between islands due to the non-normal distribution of the survey data.

Piping Plover abundances were compared to the level of beach management practices and shoreline development. Beach management practices examined include permitted and prohibited vehicular beach driving sections, and the level of beach raking. Beach raking categories include and were defined as: no raking, seasonal raking (i.e., raking only occurred during high recreational use months), and frequent raking (i.e., raking occurred during low and high recreational use months). Each beach management category was identified in the field and marked with a GPS unit. Shoreline development categories are based on the U.S. Geological Survey (USGS) Coastal Classification Atlas (U.S. Geological Survey 2005) and include: undeveloped, low-density developed (i.e., few isolated or scattered buildings per unit area with natural topography and vegetation), moderate-density developed (i.e., conditions between low and high-density development), and high-density developed (i.e., many buildings per unit area with little or no green space separating buildings). Shoreline development categories and locations were mapped and provided in PDF files from the USGS Coastal Classification Atlas website and ground truthed in the field. The cumulative length of each management practice and shoreline development category per island was measured using Google Earth Pro (Google, Inc., Mountain View, CA). Relative frequency of occurrence was calculated by tallying the occurrence of Piping Plovers in each category during each survey.

Piping Plover Distribution

To examine how Piping Plovers were distributed across each survey island, transect densities of feeding and roosting Plovers were analyzed from 26 August 2012 to 23 April 2013 (*n* = 35) and presented in bar charts. These survey dates were used in the analysis to reduce variability in Plover densities by removing data from early fall and late spring migration periods. Plover abundances (pooled across both survey islands) before and after the survey cutoff dates were distinctly lower and suggested early or late migrants (Appendix A). Transect densities were calculated by averaging survey counts of Plovers in each transect for each behavior.

The spatial distribution of feeding and roosting Piping Plover observations were analyzed to determine if feeding Plovers had a random distribution and to reveal important feed and roost sites. The spatial analysis was based on each behavior since feeding Plovers are generally observed individually on the beach and claim a small feeding territory, whereas multiple members of the Plover family, Charadriidae, are generally observed roosting in loose groups or flocks, especially in the winter. Zonick (2000) observed feeding Piping Plovers spaced 100 – 200 m apart from each other on the beach during periods of high abundance at most of his survey sites on the Texas coast. He found that Plovers located on 6.3 km of beach at San Luis Pass on Galveston Island had an average minimum spacing of 240.0 m between each Piping Plover.

The spatial distribution of feeding (n = 2014) and roosting observations (n = 600) from 26 August 2012 to 23 April 2013 surveys (n = 35) were analyzed to determine if there was any statistically significant clustering in the spatial pattern of each behavior. The mapping software, Esri ArcGIS®, version 10.2.2 (Esri, Inc., Redlands, CA) and the spatial statistic tool, optimized hot spot analysis, was used to identify areas along the beach with significant use by feeding and roosting Piping Plovers. Optimized hot spot analysis is similar to the nearest neighbor distance, in that it analyzes the location of each individual Plover observation within the context of neighboring Plover observations and identifies significant hot spots (i.e., clusters) based on the accumulation of high values. The analysis tool identifies significant hot and cold spots with 90%, 95%, and 99% confidence using the Getiss-Ord Gi* statistic.

The optimized hot spot tool used one incident point for each feeding or roosting Plover observation to ensure the analysis was not weighted disproportionately. If a

Plover observation had >1 Piping Plover with the same GPS coordinates, random points were generated within a 5 m buffer around the original GPS coordinate. Next, the tool was constrained to analyze incident points within a polygon that was drawn around each survey island and buffered 100 m around the majority of incident points. The bounding polygon allows for more precise results.

Factors Influencing Piping Plover Distribution

Analyses were conducted to determine the potential effects that habitat and anthropogenic factors have on Piping Plover distribution across islands. Data used in the analysis were densities of feeding Piping Plovers in linear beach transects (n = 34), excluding inlet transects SLP and G21, between 26 August 2012 and 23 April 2013 surveys (n = 35). These criteria were set to reduce background variability in Plover densities by removing data associated with inlet habitats, roosting flocks, and early fall and late spring migration periods.

Multiple independent environmental, recreational, and habitat variables measured within each transect were evaluated for possible inclusion in a statistical model for prediction of Piping Plover densities. One environmental variable was measured, and included tide level (mean sea level). Recreational variables included: densities of humans, vehicles, and dogs (leashed and unleashed). Habitat variables included: area of adjacent bayside intertidal flats, developed land percentage, proportional length of permitted beach driving, number of beach vehicle access points (VAP), and beach width. Environmental and recreational variables were continuous, whereas habitat variables were fixed for each transect. Intertidal flats area and the percentage of developed land were estimated with ArcGIS using NOAA's 2010 Coastal Change Analysis Program (C-

CAP) land cover imagery data (National Oceanic and Atmospheric Administration 2014). The raster-based land cover imagery provides 30-meter resolution and is comprised of 24 mapped land classes, which included intertidal areas (i.e. unconsolidated shore), wetlands, and developed lands (Figure 3). Land cover was measured in each transect within a 1 km width x 3.5 km depth area including approximately 50 m of the beach. The 3.5 km depth followed LeDee et al.'s (2008) method which used Drake et al.'s (2001) calculated mean linear distance of 3.3 km and core area of 2.9 km^2 for wintering Piping Plovers in the southern Laguna Madre of Texas.

Simple Regression and ANOVA models

To estimate how Piping Plover densities responded to the variables previously discussed, all transect data within the study period were analyzed (35 surveys x 34 transects = n = 1190). Continuous variables (i.e., environmental and recreational) were independently evaluated against Piping Plover densities using simple linear regression analysis. Continuous and discrete variables (i.e., habitat) were analyzed to compare Plover densities between islands and variables using Mann-Whitney and Kruskall Wallis non-parametric statistical tests due to the non-normal distribution of the data. In the event of a missing data point (n = 7) (e.g., humans/km), an estimated value was included that was calculated by taking an average value from the two surveys before and after the missing data point.

Multiple Regression Model

Simple and multiple regression linear models were used to analyze how different recreational uses and habitat variables in combination within transects influenced Piping Plover densities and overall distribution. To accomplish this, average values for

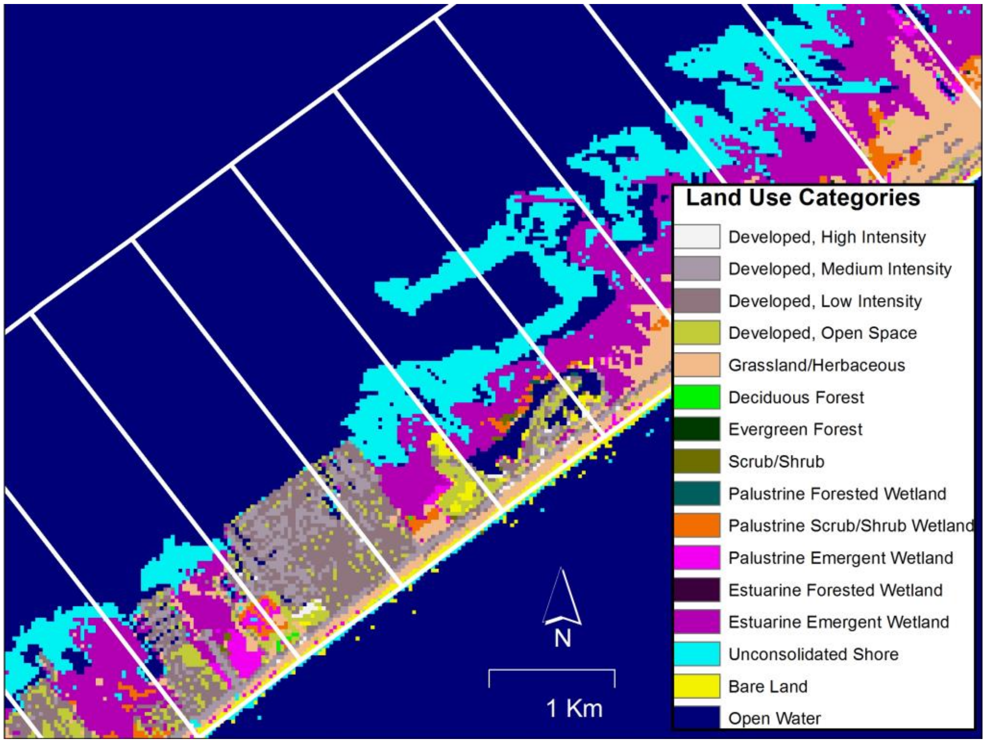


Figure 3. Land coverage raster imagery from NOAA Coastal Change Analysis Program. The white polygons represent each survey transect that was measured at an area of 1 km x 3.5 km.

continuous variables, including Piping Plover densities, for each linear transect ($n = 34$) between 26 August 2012 and 23 April 2013 surveys ($n = 35$) were used in the model analysis. This analysis approach was used by Colwell and Sundeen (2000) and Neuman et al. (2008). Tide level (msl) was not used in this analysis because, when averaged, the level only differed approximately 0.003 m from each transect, while the average daily tidal amplitude varied ± 0.6 m.

Simple linear regressions were ran on each independent variable against mean transect densities of Plover. Independent variables that significantly ($P \leq 0.05$) predicted variation in Plover densities were compared using Spearman rank-order correlation analysis to eliminate redundant variables that were significantly correlated. Independent variables that were not strongly correlated were considered for further analysis using two multiple linear regression model approaches – best subset regression and stepwise regression. These modeling approaches were used to analyze the influence of these variables on Piping Plover density in combination to assess other viable predictive models. First, best subset regression was employed to identify models with the highest R^2 values and fewer predictors. The corrected Akaike information criterion (AIC_c) was also used to compare models that offered the simplest, most parsimonious, model. Second, stepwise regression analysis ($P = 0.15$ to enter and remove) was employed to identify the most robust multiple regression model by starting with an empty model that adds or removes a variable for each step.

Prey Availability

Prey data was analyzed separately since benthic samples were not collected at all transects or during each bird survey. Benthic samples were presented as # animals/m^2 by dividing each sample abundance by 0.0285 m^2 ($A = \pi r^2$, based on PVC core radius = 0.09525 m). Descriptive statistics on benthic groups were analyzed based on all sample replicates collected (n = 366).

Prey densities were analyzed to compare differences in sample sites, seasons, and taxa groups. Site densities used in the analysis were of the mean number of invertebrates per triplicate benthic core sample (n = 122). Simple linear regression was performed to test for the response of benthic organism density to the amount of natural wrack on the beach. Mann-Whitney statistical test was used to test for differences in prey densities at site use categories of high and low Plovers, high and low human levels, and raked and unraked beach segments. To help meet assumptions of normality, the square-root transformation of the mean benthic density was used in parametric tests (e.g. simple linear regression) and untransformed count data in nonparametric tests (e.g. Mann-Whitney, Friedman). All analysis were judged statistically significant when $P < 0.05$.

RESULTS

Piping Plover Abundance

Piping Plovers were observed during 42 of the 43 beach surveys from 3 August 2012 to 14 May 2013. A total of 2757 Piping Plover observations were recorded between both sites, 70% (n = 1926) on Galveston Island and 30% (n = 831) on Follets Island. Abundances greatly increased and decreased after 22 August 2012 and 4 May 2013, respectively. Peak counts of Piping Plovers on Follets Island were observed in October ($\bar{x}$ = 2.7 birds, SE = 0.10, n = 4), while counts on Galveston Island were equally high in March ($\bar{x}$ = 3.1 birds, SE = 0.34, n = 4) and April ($\bar{x}$ = 3.1 birds, SE = 0.21, n = 4) (Figure 4).

Mean Piping Plover abundance along the 14.7 km Follets Island survey route was 19.3 birds/survey ($\bar{x}$ = 1.3 birds/km, n = 43) and 44.8 birds/survey ($\bar{x}$ = 2.1 birds/km, n = 43) along the 21 km Galveston Island survey route (Table 2). When comparing seasonal densities of Piping Plovers between islands, fall densities were not significantly different between islands (W = 168.5, P = 0.739), whereas densities were significantly higher on Galveston Island than Follets Island in the winter (W = 419.0, P = 0.001) and spring (W = 113.0, P = 0.034). When comparing each island separately, Plover density on Galveston Island did not differ between seasons (H = 0.26, P = 0.879), while densities on Follets Island were significantly higher in the fall migratory season compared to the spring (Z = 2.018, P = 0.044).

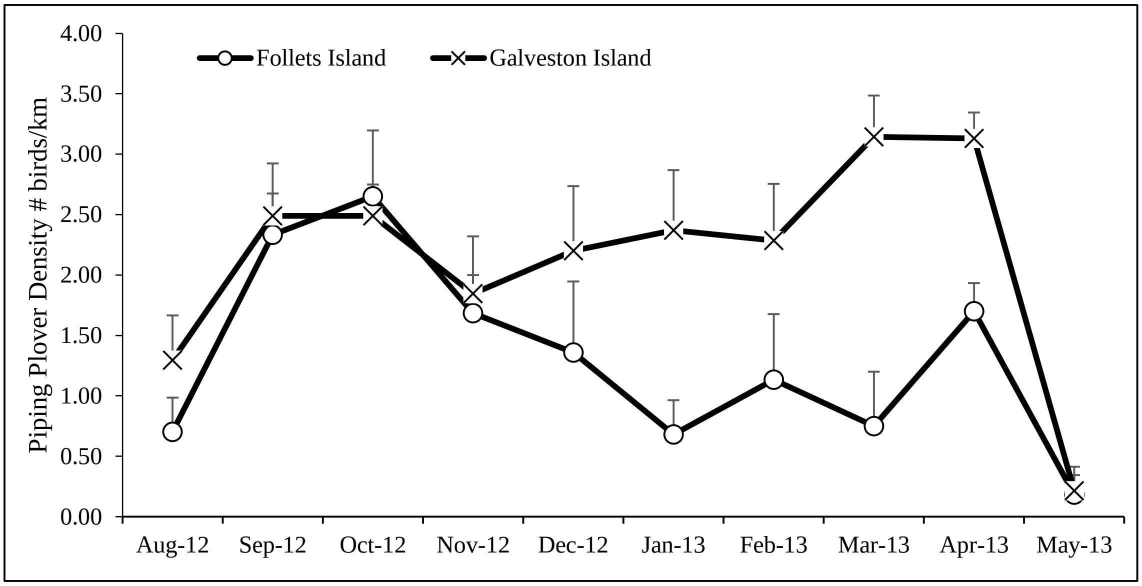


Figure 4. Mean monthly density of Piping Plovers (± SE) along the 14.7 km Follets Island and 21 km Galveston Island survey route from 3 August 2012 to 25 May 2013 (n = 4-5 surveys/month).

Table 2. Mean and max abundance and density of Piping Plovers on Follets Island and Galveston Island during the 2012-2013 nonbreeding season. Abundance is presented as the mean total count of Piping Plovers recorded at each site. Density is expressed as the number of birds/km. Data based on a total of 43 surveys, 13 (*n*) in the fall, 18 (*n*) in the winter, and 12 (*n*) in the spring.

	FALL			WINTER			SPRING			ALL	
Site	$\bar{x}$	SE	Max	$\bar{x}$	SE	Max	$\bar{x}$	SE	Max	$\bar{x}$	SE
Abundance											
Follets	27.0	4.81	54	17.9	3.77	49	13.2	3.71	36	19.3	2.47
Galveston	42.6	6.20	78	45.9	4.53	75	45.4	9.18	86	44.8	3.61
Density											
Follets	1.8	0.32	3.6	1.2	0.25	3.3	0.9	0.25	2.4	1.3	0.17
Galveston	2.0	0.30	3.7	2.2	0.22	3.6	2.2	0.44	4.1	2.1	0.17

The occurrence of Piping Plovers across various anthropogenic shoreline features are summarized in Table 3. Beach driving was permitted across the entire Follets Island survey route (except the western 125 m of inlet beach in transect SLP starting on 4 May 2013, *n* = 4 surveys), whereas it was limited to a cumulative length of 5.5 km (26%) of the Galveston Island survey route. The proportional length (14.7 km) of permitted driving on Follets Island was close to that of the prohibited driving length (15.5 km) on Galveston Island, however there were 69% more Plover observations on prohibited driving beaches on Galveston Island. Piping Plovers on Galveston Island were observed most frequently in driving prohibited beach sections (90%, *n* = 1713) and had a higher relative frequency of occurrence (*Rf* = 0.57) than in driving permitted beach sections (*Rf* = 0.43, Table 3). Beach driving on Galveston Island was mostly limited to designated beach parking areas (range 45 m – 2.6 km wide) bounded with bollards (i.e. vehicular barriers). Furthermore, beach driving on Galveston Island was mostly prohibited along developed shorelines with the exception of Galveston Island State Park's undeveloped shoreline.

The proportional length of undeveloped shoreline was 52% higher on the Follets Island survey route compared to Galveston Island, however slightly more (18%) Plover observations were made on Galveston Island's undeveloped shorelines. Nearly half (49.3%) of Plover observations on Galveston Island were on the 12.5 km of moderately developed shorelines, which consisted of a mix of beach houses, condominiums, and resorts.

Table 3. Piping Plover use based on beach management and shoreline development categories on Follets Island, TX and Galveston Island, TX during the 2012-2013 nonbreeding season. The total observations (*n*) of Piping Plovers per kilometer of respective category classification (Km) and relative frequency of occurrence (*Rf*) are listed. Data based on 43 surveys (*N*) and individual bird observations on Follets Island (*n* = 831) and Galveston Island (*n* = 1926).

	Follets Island			Galveston Island		
	n	Km	*Rf*	*n*	Km	*Rf*
Beach Driving						
Permitted	831	14.7	1.00	213	5.5	0.43
Not Permitted	-	0	-	1713	15.5	0.57
Beach Raking						
No Raking	760	13.5	0.64	887	8.9	0.38
Seasonal Raking	71	1.3	0.36	986	11.0	0.41
Frequent Raking	-	-	-	53	1.1	0.22
Shoreline Development						
Undeveloped	670	12.1	0.46	799	7.1	0.34
Low	153	2.4	0.44	163	1.2	0.19
Moderate	8	0.2	0.10	949	12.5	0.36
High	-	-	-	15	0.2	0.12

Beach raking occurred more frequently on Galveston Island, primarily during seasonally high recreational use (late spring – late summer) periods along developed shorelines. One frequently raked resort shoreline on Galveston Island measuring 190 m wide was raked every day during the study period. During that period only two single feeding Piping Plover events were observed during the winter along that shoreline. The average amount of wrack distributed on the beach (swash zone to vegetation line) at locations of observed feeding and roosting Piping Plovers was 22.2% (SE = 0.371, *n* = 1757) and 20.8% (SE = 0.949, *n* = 305), respectively. Water hyacinth (*Eichhornia crassipes*) was a common source of wrack, washing ashore in higher densities after significant rain events.

Recorded behavioral observations of feeding (*n* = 2110, 77%) and roosting (*n* = 636, 23%) Piping Plovers were pooled between both islands and analyzed in a contingency table based on their location in different land use and beach management sections (Table 4). The majority of observations were located in driving prohibited beaches for feeding (*n* = 1297, 61%) and roosting birds (*n* = 411, 65%). Where driving was permitted, Plovers were observed most on undeveloped beaches with no raking when feeding (*n* = 589, 72.4%) and roosting (*n* = 161, 71.6%). Where driving was prohibited, Plovers were observed most on moderately developed beaches with seasonal raking when feeding (*n* = 646, 49.8%), and on undeveloped beaches with no raking when roosting (*n* = 177, 43.1%) (Table 4).

Table 4. Contingency table of Piping Plover observations in beach sections with different intensities of shoreline development, beach raking, and beach driving (permitted/prohibited). Data based on a total of 2110 feeding and 636 roosting observations pooled between Follets Island and Galveston Island.

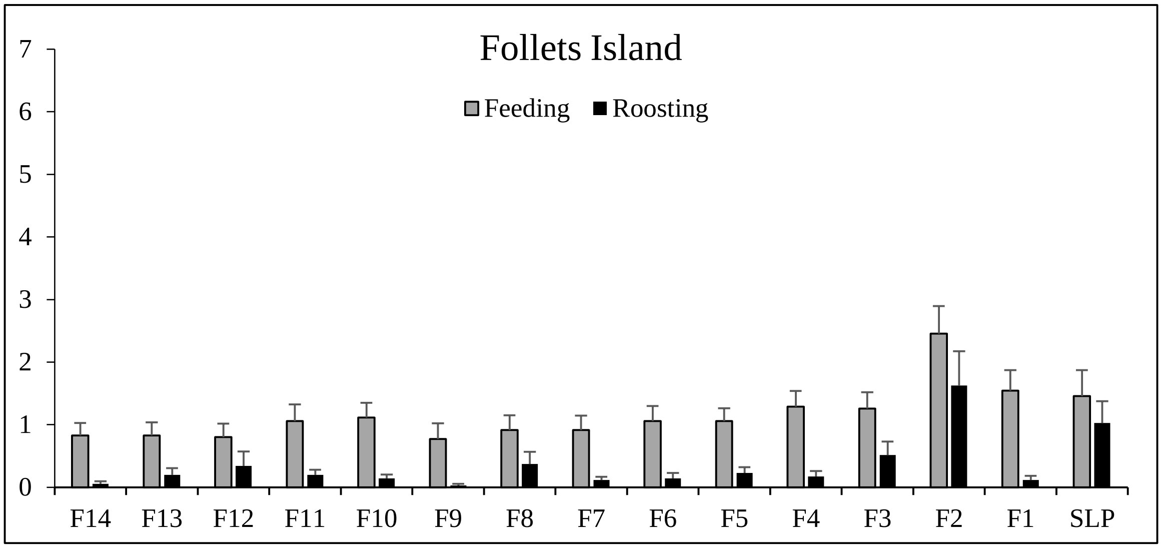
	Feeding			Roosting		
	No Raking	Seasonal Raking	Frequent Raking	No Raking	Seasonal Raking	Frequent Raking
Shoreline Development						
Undeveloped	589 / 472[a]	58 / 2	0 / 1	161 / 177	4 / 1	0 / 0
Low	112 / 0	2 / 82	0 / 3	46 / 0	0 / 65	0 / 1
Moderate	15 / 51	37 / 646	0 / 27	1 / 13	13 / 147	0 / 6
High	0 / 0	0 / 0	0 / 13	0 / 0	0 / 0	0 / 1

[a] Driving permitted / prohibited

Piping Plover Distribution

Only surveys from 26 August 2012 through 23 April 2013 (n = 35) were used in subsequent analysis to eliminate bias associated with surveys with significantly lower Piping Plover densities attributed to the start and end of fall and spring migration. Piping Plovers were observed in all transects across islands, with greater variation in densities on Galveston Island (Figures 5, Table 5). Mean densities across all transects ranged from 0.7 – 5.3 feeding birds/km ($\overline{x}$ = 1.6, n = 35) and 0.0 – 2.9 roosting birds/km ($\overline{x}$ = 0.5, n = 35). Follets Island Plover densities were slightly above average in transects closest to the San Luis Pass inlet, highest in transect F2 for both feeding ($\overline{x}$ = 2.5 birds/km) and roosting ($\overline{x}$ = 1.6 birds/km) Plovers (Figure 5a). The highest Plover densities on Galveston Island were located furthest from the inlet in transects G1 and G2 for roosting ($\overline{x}$ = 2.9 birds/km) and feeding ($\overline{x}$ = 5.3 birds/km) Plovers (Figure 5b). Both of these transects were located within the boundaries of Galveston Island State Park. Piping Plover densities decreased significantly from transect G2 to G3 (Figure 5b). Part of G3 (0.37 km) was within the Park boundaries, while the majority of the transect was within the city boundaries of Jamaica Beach.

Behavioral spatial analysis, using GIS hot spot analysis, revealed a nonrandom distribution of feeding and roosting Piping Plovers across islands. Significant (90%, 95%, 99% confidence) clusters of Plovers were identified across both survey islands, corresponding closely to high Plover densities indicated in Figure 5a, b. Feeding clusters were identified in four separate sections: (1) Galveston Island transects G1 – 0.37 km of G3 (Galveston Island State Park boundaries), (2) interspersed between G6 – G10, with the highest concentration in G7, (3) G17 – G18, and (4) Follets Island transects SLP – F2.



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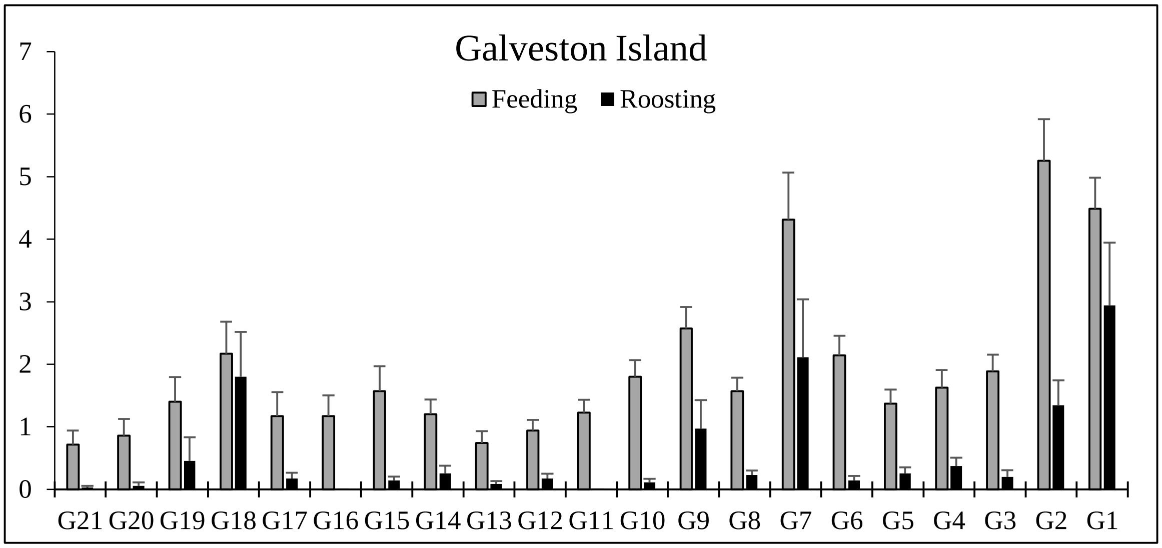


B.

Figure 5. Mean Piping Plover feeding and roosting counts (± SE) for each transect along the (A) Follets Island and (B) Galveston Island survey route during the 2012-2013 nonbreeding season. SLP and G21 are inlet transects while F14 and G1 are furthest from the inlet. Transect SLP is not a linear segment and was surveyed in its entirety (0.7 km shoreline as well as interior lagoon), so data is not on a per kilometer basis. Data from 26 August 2012 – 23 April 2013 surveys (*n* = 35).

Table 5. Mean Piping Plover and recreational densities and habitat characteristics for transects (Km) on Follets Island and Galveston Island, TX. Densities averaged from surveys 26 August 2012 to 23 April 2013 (n = 35). Transects starting with F were on Follets Island and G on Galveston Island. VAP = Vehicle Access Points.

	Feed		Roost		Humans		Vehicles		VAP	Permit Drive[b] (%)	Develop-ment (%)	Flats (ha)
Km	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE				
F14	0.8	0.20	0.1	0.04	20.5	7.54	9.2	2.47	1	100	8	54
F13	0.8	0.21	0.2	0.11	9.0	3.48	4.6	1.69	0	100	2	13
F12	0.8	0.22	0.3	0.23	7.8	2.56	5.4	1.54	1	100	2	40
F11	1.1	0.27	0.2	0.08	6.5	2.47	2.9	0.90	1	100	3	42
F10	1.1	0.23	0.1	0.06	2.7	1.00	1.9	0.63	2	100	4	29
F9	0.8	0.25	0.0	0.03	2.2	0.92	1.5	0.44	2	100	7	39
F8	0.9	0.23	0.4	0.20	5.1	1.41	2.9	0.85	1	100	9	23
F7	0.9	0.23	0.1	0.05	1.8	0.76	1.6	0.60	0	100	5	23
F6	1.1	0.24	0.1	0.08	2.1	1.05	1.3	0.42	0	100	6	22
F5	1.1	0.20	0.2	0.09	4.7	1.68	2.4	0.72	1	100	7	20
F4	1.3	0.25	0.2	0.09	1.8	0.78	1.3	0.47	1	100	1	30
F3	1.3	0.26	0.5	0.21	0.9	0.36	0.7	0.21	2	100	1	39
F2	2.5	0.44	1.6	0.54	3.6	1.57	1.7	0.54	1	100	1	44
F1	1.5	0.33	0.1	0.07	3.1	0.82	0.9	0.26	0	100	5	40
SLP	1.5	0.41	1.0	0.34	19.9	5.62	12.7	3.00	1	100	31	106
San Luis Pass Inlet												
G21	0.7	0.23	0.0	0.03	26.5	7.72	14.8	3.26	1	100	0	184
G20	0.9	0.27	0.1	0.06	15.7	4.85	7.0	1.78	1	100	24	133
G19	1.4	0.40	0.5	0.38	8.4	2.69	2.4	0.90	0	68	29	34
G18	2.2	0.51	1.8	0.71	13.1	6.05	0.2	0.05	0	0	23	24
G17	1.2	0.38	0.2	0.10	15.1	4.84	0.7	0.19	0	10	28	28
G16	1.2	0.33	0.0	0.00	12.9	4.67	6.2	1.77	2	100	6	32
G15	1.6	0.40	0.1	0.06	6.7	1.77	1.4	0.39	1	4	21	25
G14	1.2	0.23	0.3	0.12	11.2	3.51	3.0	0.81	1	9	40	27
G13	0.7	0.19	0.1	0.05	16.5	5.19	4.9	1.54	2	14	45	19
G12	0.9	0.17	0.2	0.08	13.7	4.88	0.2	0.05	0	0	86	2
G11	1.2	0.20	0.0	0.00	15.4	5.54	3.3	1.06	1	5	52	29
G10	1.8	0.27	0.1	0.05	4.4	1.25	1.3	0.38	1	10	35	52
G9	2.6	0.34	1.0	0.46	2.3	0.67	0.2	0.06	0	0	10	47
G8	1.6	0.21	0.2	0.07	12.4	3.13	0.1	0.04	0	0	18	42
G7	4.3	0.75	2.1	0.92	4.9	2.37	0.2	0.10	0	0	7	68
G6	2.1	0.31	0.1	0.07	6.6	1.84	0.5	0.17	0	0	9	63
G5	1.4	0.22	0.3	0.09	12.6	4.73	0.8	0.31	0	0	10	46
G4	1.6	0.28	0.4	0.14	14.3	5.56	6.4	2.31	1	63	14	52
G3	1.9	0.27	0.2	0.11	19.3	6.93	8.2	2.54	2	63	69	13
G2	5.3	0.67	1.3	0.40	6.6	1.78	0.4	0.10	0	0	7	67
G1	4.5	0.50	2.9	1.00	20.5	7.94	0.8	0.28	0	0	7	56

Roosting clusters were identified in four separate sections: (1) transects G1 – G2, (2) G7, (3) G17 – G18, and (4) F2. Maximum roost counts observed in one flock (i.e., one spatial observation of roosting birds grouped together during a survey) in the former three Galveston sections were 25, 22, and 17 Plovers, respectively; smaller roost flocks (6-8 birds) were observed on Follets Island in transect SLP and F2. GIS spatial outputs of significant cluster are displayed in Appendix B. Distributional patterns for both behaviors indicate clusters were located adjacent to or near higher areas of intertidal flats, while aggregated within longer stretches of beach with prohibited driving and low frequency of vehicle access points, and relatively low development (Appendix B, Table 5).

Factors Influencing Piping Plover Distribution

Data of Piping Plover and recreational densities and habitat characteristics from each transect surveyed across both islands are summarized in Table 5. Only linear beach transects (n = 34, excludes inlet transects G21 and SLP) from the aforementioned surveys dates (n = 35) were examined to investigate the relationship between feeding Piping Plover densities and measured recreational densities, beach management practices and habitat features.

Mean recreational transect densities pooled across surveys (n = 35) ranged from 0.9 – 20.5 humans/km, 0.1 – 9.2 vehicles/km, and 0.0 – 1.4 dogs/km (Table 5). Survey transect densities of humans/km were significantly higher on Galveston Island than Follets Island ($H = 73.25$, $n = 1190$, $P \leq 0.001$), while vehicle densities were significantly higher on Follets Island ($H = 12.84$, $n = 1190$, $P \leq 0.001$). Significant differences in seasonal recreation densities pooled between surveys and island were detected for humans ($\chi^2{}_2 = 140.08$, $n = 1190$, $P \leq 0.001$) and vehicles ($\chi^2{}_2 = 125.02$, $n = 1190$, $P \leq 0.001$), both higher and lower in the fall and winter, respectively. Furthermore, independent analysis showed fall densities of vehicles, humans, and dogs each exhibited a significant linear ($P \leq 0.001$), yet weak, negative relationship with fall densities of Piping Plovers, whereas no significant linear relationship was detected in the winter and spring season (Table 6). When combining transect densities from all seasons, only densities of vehicles exhibited a significant linear, yet weak, negative relationship with Piping Plover densities (Table 6). See Appendix C for scatterplots showing the relationship between Piping Plover and recreational densities by season and all seasons combined. The number of vehicle access points (VAP) to the beach ranged from 0 – 2 VAP per transect (Table 5). Plover densities in transects with no VAP were higher and significantly different than those with 1 and 2 VAP ($\chi^2{}_2 = 24.92$, $n = 1190$, $P \leq 0.001$).

We conducted 17 weekday and 18 weekend surveys. Mean weekend transect densities ($n = 612$) of humans ($\overline{x} = 15.8$/km, SE = 1.23), vehicles ($\overline{x} = 4.2$/km, SE = 0.36), and dogs ($\overline{x} = 1$/km, SE = 0.07) were significantly higher than weekday densities ($n = 578$), each at least 80% higher on weekends versus weekday surveys. Weekend vehicle densities exhibited a significant negative relationship, however slight, with Piping Plover densities (Adj. $R^2 = 0.190$, $P \leq 0.001$, df = 610). Data from two holiday weekends surveys (Labor Day - 2 September 2012 and Spring Break -16 March 2013) were examined to determine if significant relationships were observed between Plover and humans, vehicle and dog densities. Labor Day densities of Plovers exhibited a significant negative relationship with densities of humans (Adj. $R^2 = 0.306$, $P \leq 0.001$, df = 33),

Table 6. Mean recreational densities and simple linear regression coefficients pooled between Follets Island and Galveston Island linear transects from surveys 26 August 2012 to 23 April 2013 (*n* = 1190).

	Summary			Simple Regression		
Season	$\bar{x}$	SE	*n*	Coef.	Adj. R^2	*P*
Fall						
Humans	19.37	1.95	306	-0.011	0.040	≤ 0.001
Vehicles	5.8	0.59	306	-0.051	0.081	≤ 0.001
Dogs	0.93	0.09	306	-0.229	0.037	≤ 0.001
Leashed	0.41	0.06	306	-0.204	0.001	0.043
Unleash	0.52	0.06	306	-0.322	0.032	0.001
Winter						
Humans	2.92	0.22	612	-0.008	0.000	0.639
Vehicles	0.91	0.07	612	-0.087	0.002	0.115
Dogs	0.36	0.03	612	0.074	0.000	0.516
Leashed	0.19	0.02	612	0.291	0.003	0.081
Unleash	0.17	0.02	612	-0.151	0.000	0.396
Spring						
Humans	10.78	1.64	272	0.01	0.008	0.078
Vehicles	2.55	0.45	272	-0.007	0.000	0.718
Dogs	0.8	0.1	272	0.147	0.006	0.100
Leashed	0.47	0.07	272	0.187	0.004	0.155
Unleash	0.33	0.05	272	0.232	0.003	0.184
All						
Humans	8.95	0.67	1190	-0.001	0.000	0.732
Vehicles	2.54	0.19	1190	-0.028	0.006	0.004
Dogs	0.61	0.04	1190	0.016	0.000	0.753
Leashed	0.31	0.02	1190	0.101	0.001	0.181
Unleash	0.30	0.02	1190	-0.078	0.000	0.344

vehicles (Adj. $R^2 = 0.210$, $P = 0.004$, df = 33), and dogs (Adj. $R^2 = 0.150$, $P = 0.013$, df = 33). Mean densities on Labor Day weekend across both islands were 69.5 humans/km (SE = 11.0), 17.4 vehicles/km (SE = 3.41), 1.7 dogs/km (SE = 0.38) and 1.4 Plovers/km (0.30). Spring Break weekend densities of feeding Piping Plover showed no significant relationship with humans, vehicles, or dogs (Appendix D).

Piping Plover densities were positively influenced with tide height (msl), increasing with rising tides (Adj. $R^2 = 0.068$, $P \leq 0.001$, df = 1189). Monthly mean tide levels were significantly lower from January through April 2013 (Appendix E). Mean intertidal flats area was 26% larger on Galveston Island ($\bar{x} = 43.0$ ha, SE = 6.23, $n = 20$) than Follets Island ($\bar{x} = 33$ ha, SE = 3.07, $n = 14$). The largest area of intertidal flats used in the analysis was in transect G20 (133 ha) on Galveston Island adjacent to the San Luis Pass inlet. Larger amounts of intertidal flats area were found at inlet transects SLP (106 ha) and G21 (184 ha), however their data was not used in this analysis. Transect G12 had the lowest area of intertidal flats (2 ha) and highest amount of development (86%), a weak but significant correlation between these variables (Spearman Rho = -0.173, $P = \leq 0.001$).

Regression Models

The final effects of recreational and habitat parameters on Piping Plover densities across both islands were evaluated using single independent variable linear regression models with averaged values for continuous factors from the aforementioned survey dates (n = 35) for each transect ($n = 34$) (Table 7, Appendix F for scatterplot graphs). Mean transect densities of Piping Plovers exhibited significant negative relationships with three factors: mean vehicle density (Adj. $R^2 = 0.114$, $P = 0.029$, df = 33), proportion

Table 7. Simple linear regression coefficients between mean Piping Plovers transect densities and measured variables at linear beach transects on Follets and Galveston Island during the 2012-2013 nonbreeding season. Data from 26 August 2012 – 23 April 2013 surveys, excluding roosting Plover observations and all data from inlet transects SLP and G21.

Factor	Coef.	Adj. R^2	*P*	*df*
Recreation				
Mean Vehicles (#/km)	-0.161	0.114	0.029	33
Mean Humans (#/km)	0.003	0.000	0.920	33
Mean Dogs (#/km)	0.005	0.000	0.992	33
Leashed	1.034	0.020	0.204	33
Unleashed	-1.985	0.069	0.073	33
Habitat Use				
Permitted Driving (%/km)	-1.146	0.224	0.003	33
Vehicle Access Points (#/km)	-0.545	0.116	0.028	33
Inlet Distance (km)	0.095	0.199	0.005	33
Intertidal Flats Area (ha)[a]	0.016	0.089	0.048	33
Mean Beach Width (m)	-0.006	0.011	0.248	33
Developed Land (%)[a]	-0.768	0.000	0.415	33

[a] Data from NOAA Coastal Change land coverage data; area analyzed for each transect = 1 km x 3.5 km.

of permitted driving (Adj. $R^2 = 0.224$, $P = 0.003$, df = 33), and vehicle access points (Adj. $R^2 = 0.116$, $P = 0.028$, df = 33). Mean transect densities of Piping Plovers exhibited a positive relationship with intertidal flats area (Adj. $R^2 = 0.089$, $P = 0.048$, df = 33) and inlet distance (Adj. $R^2 = 0.199$, $P = 0.005$, df = 33). When examining the influence of each factor on mean Plover density by island, Follets Island mean transect densities of Piping Plover ($n = 14$) were negatively influenced with inlet distance (Adj. $R^2 = 0.451$, $P = 0.005$) and beach width (Adj. $R^2 = 0.291$, $P = 0.027$), whereas mean transect densities of Piping Plovers on Galveston Island ($n = 20$) were positively influenced by inlet distance (Adj. $R^2 = 0.343$, $P = 0.004$) and negatively influenced by developed land (Adj. $R^2 = 0.185$, $P = 0.033$) and vehicle access points (Adj. $R^2 = 0.140$, $P = 0.058$).

To understand how recreational densities, beach management practices, and habitat features collectively influenced Piping Plover densities and distribution across both survey islands, two multiple linear regression modeling approaches, best subset and stepwise, were used to select the most parsimonious model/s for predicting Piping Plover densities. Significant factors from Table 7, excluding inlet distance and including developed land, were analyzed in best subset regression to understand how factors predicted Piping Plover densities. Inlet distance was excluded from the analysis because it did not appear to be a significant driver in Plover distribution across both islands since Plovers densities were significantly higher away from the inlet on Galveston Island. Developed land was included in the regression to evaluate the influence of development on Piping Plover distribution, especially since developed land on Galveston Island had a significant negative relationship on mean Piping Plover densities. Spearman rank-order correlation analysis was first used to reveal any significant correlation between independent factors (Appendix G).

After reviewing the best subset model output in Table 8, three factors were included in the stepwise regression model: proportion of permitted driving, intertidal flats area, and developed land. Vehicle densities and vehicle access points were excluded from the model because they were highly correlated with proportion of permitted driving (Coef. = 0.303, $P \leq 0.001$; Coef. = 0.505, $P = 0.002$, respectively). Furthermore, proportion of permitted driving was more correlated with Piping Plover densities when independently evaluated. The final stepwise regression model selected proportion of permitted driving ($P \leq 0.001$) and developed land ($P = 0.005$) as the most significant factors influencing the variability in Piping Plover transect densities across both islands. The combined stepwise model explained 38.4% (Adj R^2) of the variance in Plover density and the equation is as follows: Mean Piping Plover densities = 2.960 – 1.640 (permitted driving) – 2.495 (Developed Land). Although stepwise did not select intertidal flats as a significant predictor in this model, it contributed to 40.5% of variation in Piping Plover distribution when included in the model (Table 8).

Prey Availability

Sediment analysis identified no differences between site, category, or treatment. Sediment size was fairly consistent at all sites, averaging 15.02 percent fines/site (SE = 0.634, $n = 57$). Total benthic prey density varied highly between months, ranging from 725 animals/ m^2 in October to 12,496 animals/m^2 in May (Figure 6). Total prey density differed between seasons, with densities significantly higher in the spring sample months (March – May) than the fall and winter sample months ($Z = 1.834$, $P \leq 0.001$).

Table 8. Best subset models of variables best predicting mean transect densities of feeding Piping Plovers on Follets Island and Galveston Island during the 2012-2013 nonbreeding season. Analysis based on transect data from surveys between 26 August 2012 – 23 April 2013, excluding roosting Plover observations and inlet transects SLP and G21 (*n* = 34).

Mean Vehicles/km	Proportion of Permitted Driving	Vehicle Access Points	Intertidal Flats Area (ha)	Developed Land (%)	Adj R^2	AIC_c
	X				22.4	7.69
		X			11.6	6.90
	X			X	38.4	10.21
	X		X		31.2	9.99
	X		X	X	40.5	13.11
	X	X		X	36.6	12.99
X	X		X	X	39.1	16.10
	X	X	X	X	38.8	16.09
X	X	X	X	X	37.1	19.30

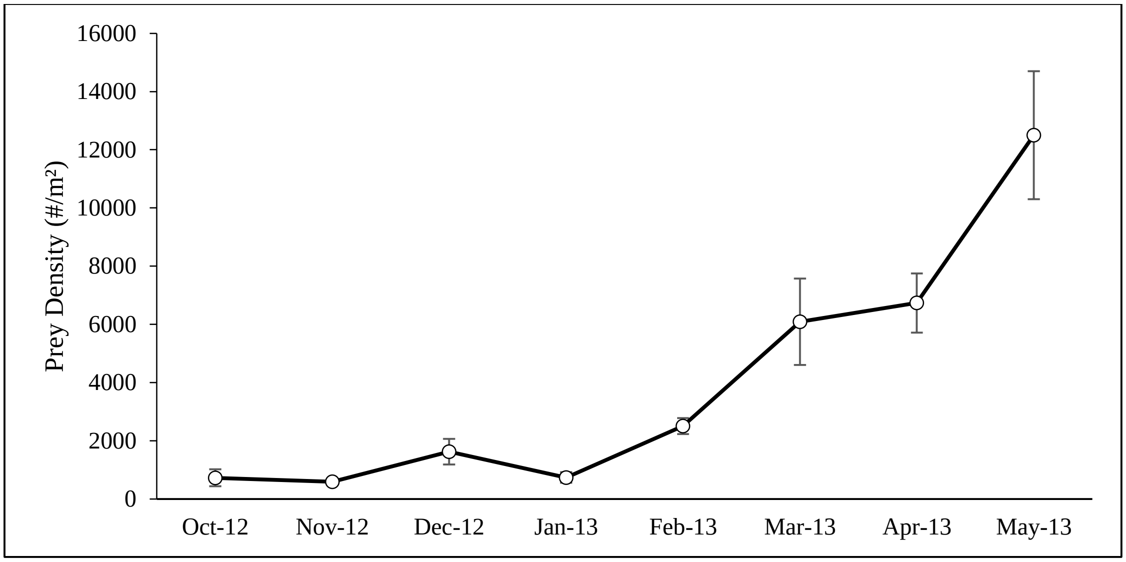
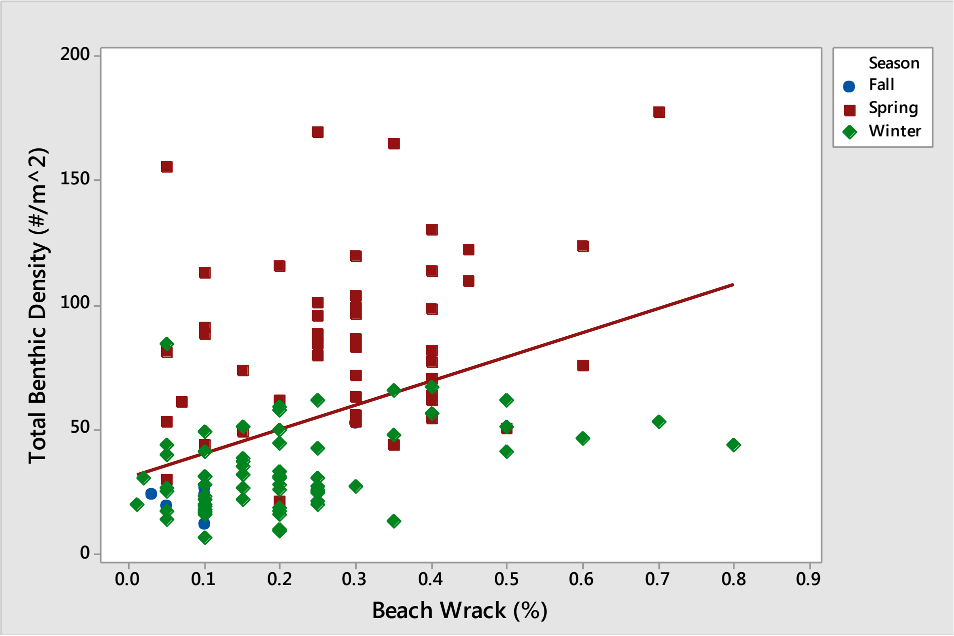


Figure 6. Mean prey density (± SE) in benthic cores for each sample month from all sample sites on Follets Island and Galveston Island.

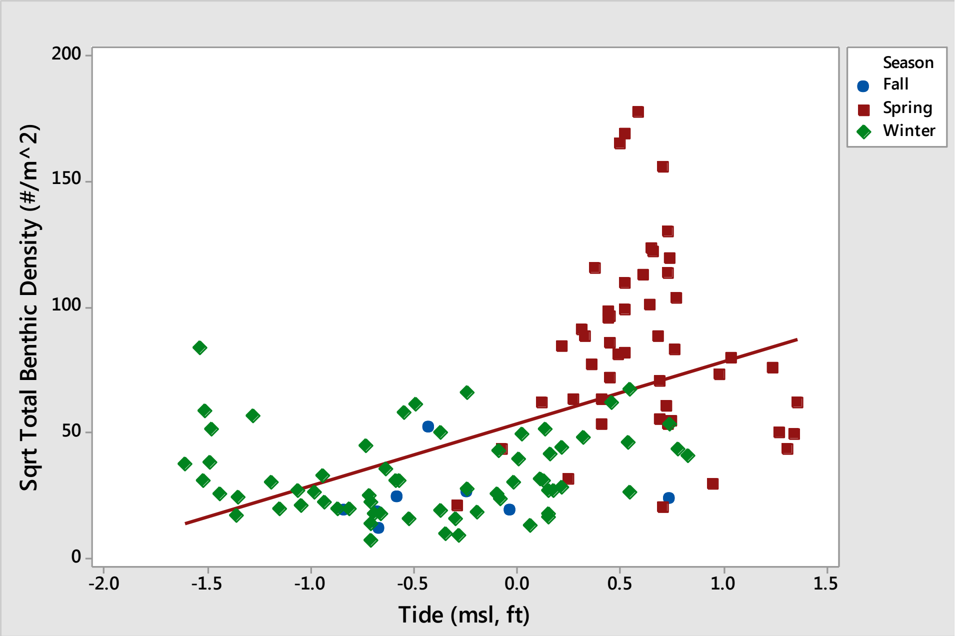
Amphipods were the most abundant group and dominated by the family Haustoriidae, with a mean density of 3,658 animals/m² (SE = 300, $n = 366$), relative sample density of 0.87 and sample frequency of 0.95. Large Haustoriidae counts were usually associated with local blooms, reaching a maximum site density of 28,477 animals/m² in May. Polychaete worms were the second most abundant group, although significantly lower than crustacean densities, with a mean density of 129 animals/m² (SE = 44.9, $n = 366$), relative density of 0.03 and sample frequency of 0.47. Insects were rare and collected in only 14 samples. Planktonic invertebrates were identified in 35 samples and used in the analysis due to their low occurrence and their potential use as prey species by Plovers.

In relation to total benthic density, no significant differences were detected between low and high use sites by Plovers (PE = 111.1, $W = 3761.5$, $P = 0.716$), or raked and unraked beach sites (PE = -257.3, $W = 3652.0$, $P = 0.411$). Environmental variables were compared independently with benthic site densities. There was a significant increasing trend in benthic density with an increase in beach wrack (Adj. $R^2 = 0.166$, $P \leq 0.001$, df = 121) and rising tides (Adj. $R^2 = 0.239$, $P \leq 0.001$, df = 121). These relationships were displayed in a scatterplot graph by sampling season and revealed the increasing trend in benthic density was more pronounced during the spring migratory season when benthic density was significantly highest (Figure 7).

Taxa groups were analyzed by site, giving particular attention to amphipods because of their dominance across sites and polychaetes for their reported prey preference by Piping Plovers (Figure 8, 9, Appendix H). No significant differences were detected in polychaete or amphipod densities when comparing all sites, Plover use, or beach

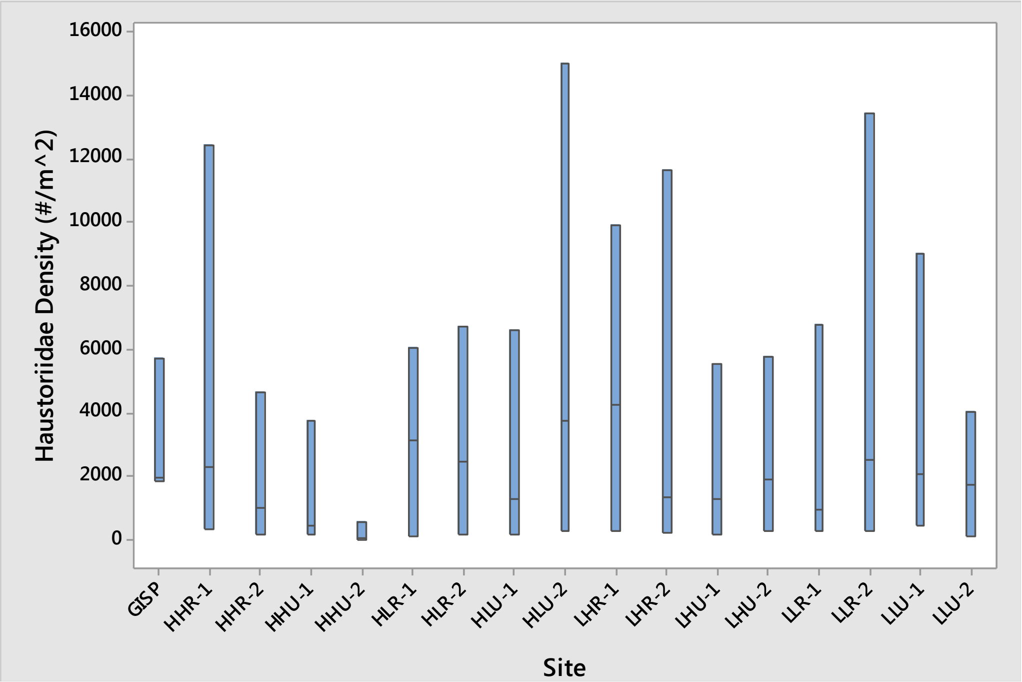


A.

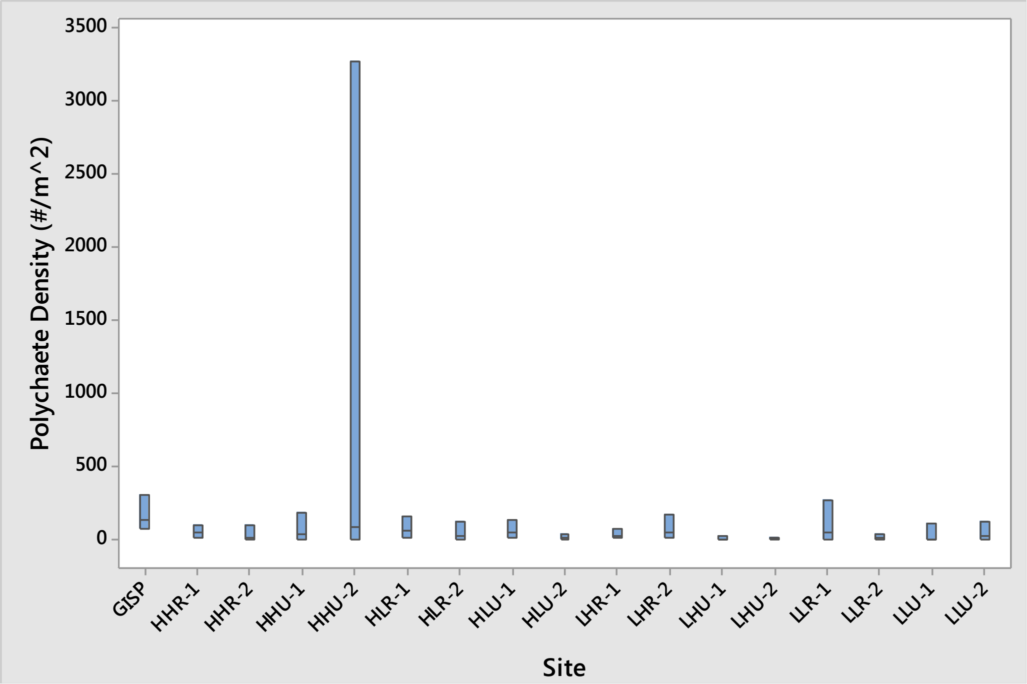


B.

Figure 7. Scatterplot showing the relationship between benthic density and (A) beach wrack (simple linear regression fitted line: Adj. $R^2 = 0.166$, $P \leq 0.001$, df = 121) and (B) tide level (simple linear regression fitted line: Adj. $R^2 = 0.239$, $P \leq 0.001$, df = 121) from benthic sample sites across Follets Island and Galveston Island ($n = 122$). Data from 19 October 2012 – 20 May 2013 collection events ($n = 8$).



A.



B.

Figure 8. Boxplot of (A) Haustoriidae and (B) polychaete density showing the 95% confidence interval of the median from benthic sample sites across Follets Island and Galveston Island (*n* = 122). Data from 19 October 2012 – 20 May 2013 collection events (*n* = 8).

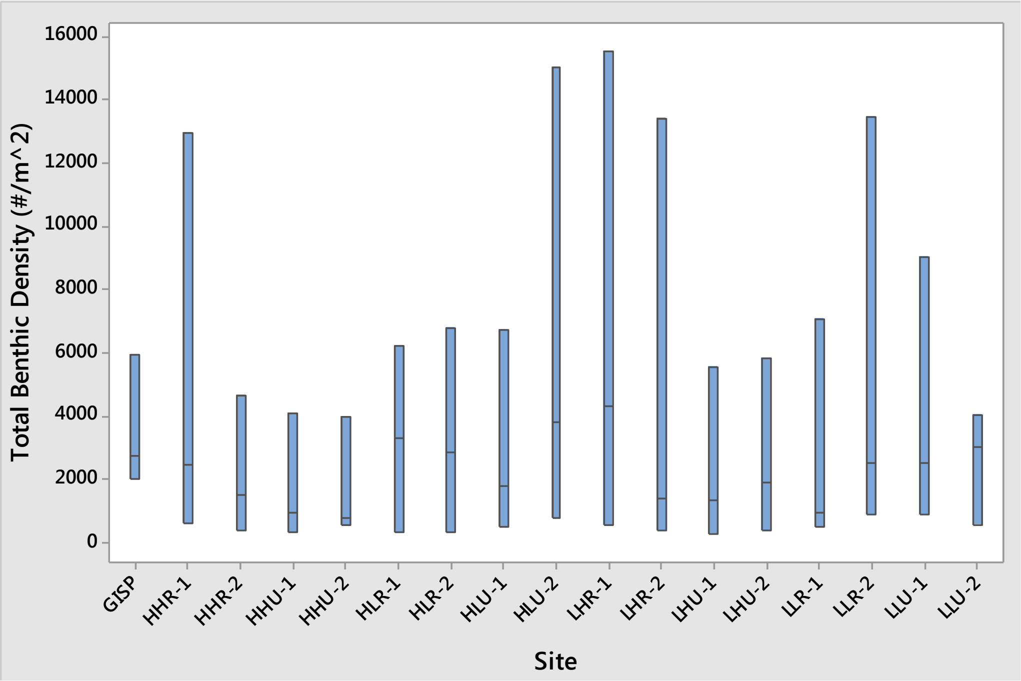


Figure 9. Boxplot of total benthic density showing the 95% confidence interval of the median from benthic sample sites across Follets Island and Galveston Island (*n* = 122). Data from 19 October 2012 – 20 May 2013 collection events (*n* = 8).

management. Site HHU-2, located in transect SLP at the San Luis Pass inlet, had the lowest amphipod density ($\bar{x}$ = 214, SE = 125.30, *n* = 7) and highest polychaete density ($\bar{x}$ = 1357, SE = 955.02, *n* = 7, Appendix H). Although not significant, mean amphipod densities were higher at raked sites ($\bar{x}$ = 4567, SE = 822, *n* = 60) compared to unraked sites ($\bar{x}$ =2804, SE = 492, *n* = 62).

DISCUSSION

This study documented a nonrandom and aggregated distribution of Piping Plovers across the Gulf beaches of Follets and Galveston Island. We observed differences among feeding and roosting densities and distribution of Piping Plovers along Follets and Galveston Islands. The data and statistical models suggest that the anthropogenic influences from beach driving and development were the most important factors influencing the distribution of Piping Plovers across Follets Island and Galveston Island, while the proximity to large areas of intertidal flats may be a contributing factor in site selection. These results are primarily supported by the analysis of abundance and distribution across islands (Figure 5a,b, Table 5) and further supported by hot spot analysis results that revealed clusters of feeding and roosting Plovers on beaches with relatively low development and prohibited beach driving, that are also adjacent to or near bayside intertidal flats (Appendix B). Colwell (2010) states that low-intensity, as well as chronic levels of disturbance can influence shorebirds to move to alternate locations that offer greater foraging opportunities and safer resting habitats. Findings from this study differ from those of Zonick (2000) who found amore even distribution pattern of Piping Plovers along the Texas coast.

Anthropogenic Influences

Vehicles and Beach Driving

Regression analysis results supported the hypothesis that beaches with increased vehicle densities and beach driving had lower densities of Piping Plovers. Piping Plover densities on Galveston Island varied across transects and were noticeably higher (often by as much as 50%) within the 15.5 km of beach with prohibited driving, than the Plover densities on Follets Island's 14.7 km of beach with permitted driving. Furthermore, over half of feeding (61%) and roosting (65%) observations were observed on prohibited driving beaches, all from Galveston Island. The highest densities of Piping Plovers on Galveston Island were recorded within Galveston Island State Park (transects G1, G2 and part of G3) where vehicles are prohibited. In contrast, Plover densities and clusters significantly decline outside of park boundaries in transect G3 at the large residential development of Jamaica Beach (Appendix B) where vehicular driving and use is permitted (Figures 5a, Table 5).

These findings agree with other nonbreeding Piping Plover studies which have documented similar negative relationships with vehicles. Elliott (1996) reported a negative relationship between Piping Plover and vehicle densities ($r = -0.234$, $P < 0.05$) at Surfer Beach on Mustang Island, Texas, a popular beach with relatively heavy vehicular traffic. Zonick (2000) also found that vehicle density, measured as an index of human disturbance, was the most important factor negatively affecting Piping Plover abundance at his study sites along the Texas coast. Newstead and Vale (2014) reported fall densities of Piping Plovers considerably higher (approximate range 4 – 5 birds/km) within a 7 km section of beach closed to vehicles within Padre Island National Seashore in contrast to areas where vehicle driving is permitted (approximately 2.5 – 3 birds/km). Burger and Niles (2014) found that vehicles, followed by people walking or jogging, were the primary causes of stress to migratory shorebirds. They also documented higher abundances of four shorebird species, including the threatened Red Knot, on a segment of beach closed to vehicles in comparison to remaining segments where driving was permitted. Experimental studies that temporarily closed sections of a beach to vehicles documented a more uniform distribution and increase in shorebird density (Tarr et al. 2010, Burger and Niles 2014). Williams et al. (2004) similarly documented an increase in the number of breeding shorebirds immediately after ORVs were banned from beaches in South Africa.

Disturbance from vehicles has been shown to negatively influence roosting behaviors of nonbreeding shorebirds (Tarr et al. 2010), shift their preferred roost location within beach habitats, and reduce shorebird abundance (Pfister et al. 1992). For instance, Zonick (2000) found that ORV density negatively influenced roosting abundance of Piping Plovers on Texas beaches. Cohen et al. (2008) observed Piping Plovers rarely roosting on the ocean beach north of Oregon Inlet in North Carolina where ORV use was permitted, and instead observed Plovers roosting on the south side of the inlet, up to 4.5 times farther from preferred foraging sites.

A similar distribution pattern was observed in this study at the San Luis Pass Inlet. Roosting densities of Piping Plovers on the northeast side of the inlet were higher in transects G18 (1.8 birds/km) and considerably lower in transect G19 – G21 (range 0.0

– 0.5 birds/km), even though G18 was 2.5 times farther from prime foraging areas at the bayside intertidal flats at San Luis Pass and along the developed shoreline of Pointe West Resort. Transect G17 – G18 prohibited beach driving while permitted in transect G19 – G21, often observing ORV’s and 4x4 vehicles driving on the dunes, especially during peak recreation season when Piping Plovers are most abundant on the beach. Colwell (2010) suggests high quality roost sites are those in close proximity to prime foraging areas, saving shorebirds time and energy, and in open habitats with unobstructed views that allow birds to scan effectively for danger. Data from this study may suggest that Plovers may make a trade-off between incurring added energy costs of traveling longer distances to prime bayside foraging areas from roost sites with prohibited beach driving in exchange for less disturbance and danger while roosting.

The variation of Piping Plover densities between Galveston and Follets Island may also be explained by the differences in how vehicle access points are utilized to manage vehicular driving. The distribution of Piping Plovers on Galveston Island showed to peak and cluster away from or in between designated beach parking areas, especially for roosting birds. This may suggest that Piping Plovers are avoiding areas of increased disturbance from vehicles, people, or dogs that tend to concentrate around these parking areas. In contrast, driving on Follets Island is not constrained to beach parking areas but occurs along the entire beachfront, allowing vehicles to enter and exit the beach at different vehicle access points. Thus, with respect to human disturbance, there may be few or no areas of high versus low quality habitat on Follets Island because all beach habitat are somewhat equally affected by driving. This predictability of disturbance near parking areas, even in the winter when recreational use is low, may increase the value and habitat quality in nearby transects with no driving or parking areas, therefore increasing Piping Plover densities.

Other studies have also shown shorebird distribution influenced by high use beach access points. Burger and Niles (2014) documented higher abundances of shorebirds in a section of beach located furthest away from where people could enter the beach. Similarly, Lafferty (2001) showed the density of wintering western Snowy Plovers in Santa Barbara, California to be lower near four pedestrian beach access trailheads in comparison with other areas where Plovers roosted, as well as a 16-fold increase in disturbance rate on this beach in comparison with beaches with little to no public access.

Human Recreation

In this study human or dog densities did not have a significant negative impact on Piping Plover distribution when using data pooled across seasons, however a slight, yet significant negative relationship was detected in the fall migratory season when recreation densities were highest (Table 6). This may suggest another analytical approach might be necessary to determine the full relationship of human recreation on Piping Plover distribution. Similar studies that combined migratory and winter data in their analysis, or just analyzed winter data, also found no relationship between human densities and shorebird distribution (Colwell and Sundeen 2000, Neuman et al. 2008, Yasue et al. 2008). In contrast other studies found humans negatively influenced shorebird distribution during the migratory season (Cestari 2014, Martín et al. 2015) and year-round (Cornelius et al. 2001, Lafferty et al. 2006).

During this study holiday weekends occurred during the migratory season. This study showed Labor Day densities of people did have a negative effect on Piping Plovers.

Spring Break densities of people did not appear to negatively influence Piping Plovers, however the survey was conducted earlier in the day when recreational densities were lower compared to those observed after the survey was completed. Therefore, the Spring Break survey may not have fully captured the effects humans may have had on Piping Plovers. No inclement weather or distinctly low tides occurred during these surveys that may have influenced their presence on the beach.

Human Development

Based on the statistical analysis of the data from this study, there is sufficient evidence to support the conclusion that higher amounts of land development was inversely related to lower densities of Piping Plovers. During this study, transect G12 had a lower density of Piping Plovers ($\overline{x}$ = 0.9 birds/km), in relation to other transects on Galveston Island, and also possessed the lowest area of intertidal flats (2 ha) and highest percentage of human development (86%). Few studies have evaluated human development as a factor when analyzing Piping Plover or other shorebird distributions. LeDee (2008) found urbanization negatively influenced the abundance of nonbreeding Piping Plovers at thirty-one sites along the Gulf of Mexico from South Padre Island, Texas to Marco Island, Florida. On the upper Texas coast, Arvin (2010) noted lower Piping Plover detections on beaches with significant beachfront development. Drake et al. (2001) seldom observed Piping Plovers at tidal flats adjacent to developed areas on South Padre Island, Texas. Although Foster et al. (2009) did not explicitly evaluate the influence of human development while analyzing 29-year coastal bird abundance trends on a mid-coast barrier island, they did report a significant decline in 10 bird species including Piping Plovers during a period of rapid development. A study on resident and migratory shorebirds in Spain documented a reduction in shorebird and gull densities in urban compared to non-urban beach transects (Martin et al. 2015). It should be noted that during this study, development was significantly positively correlated with human and dog densities. So, although other studies may not have evaluated the influence of development directly reported human and dog densities may represent an indirect indicator of the amount of development within their study areas and associated influence on the distribution of nonbreeding shorebirds.

In summary the data from this study showed that Piping Plovers frequently used undeveloped and moderately developed shorelines on both islands in comparison to heavily developed areas. Moderately developed shorelines were mostly two – three rows of beach houses parallel to the shoreline and seaward of the highway. The beach houses were mostly weekend homes, with recreational use fluctuating with the weekend and decreasing during the winter. Furthermore, aerial imagery and field observations of frequented roost sites on developed shorelines showed similar habitat features, a wider buffer of naturally vegetated shoreline features between the roosting Plovers and the first row of houses. Although this observation was not quantitatively measured or statistically analyzed, it is worth noting this habitat trend for roosting Plovers. It is possible Piping Plovers were selecting areas of the beach that offer a greater distance from tall anthropogenic features (e.g., house), either for more open habitat with unobstructed views so they can effectively scan for danger or for acting as a buffer from human caused disturbances. From a management perspective, when shoreline development cannot be prevented, increasing the buffer distance from the start of development could potentially reduce negative effects on Plover use along mix-developed beach sections and reducing limitations on their distribution.

Beach Raking

During this study, beach raking was mostly localized on developed shorelines (i.e. adjacent to housing developments) and occurred most in the warmer months when recreation was highest. It was these housing developments that controlled the frequency of beach raking, as the respective municipal entities did not rake the beaches along most of the survey routes, except in the city of Jamaica Beach. In the past the city of Galveston raked the majority of beaches within their city limits but this management practice ceased soon after Hurricane Ike hit in 2008 (M. Rabago, Galveston Park Board of Trustees, personal communication). Now, persons or neighborhood associations must obtain a beach raking permit through the city and pay contractors to rake their respective beachfront. As a result, more shorelines were left unaltered and unraked. This management switch, along with the seasonal frequency of beach raking may have made previously raked developed shorelines more suitable to Piping Plovers.

Beach raking during the peak migratory season may have a negative impact on benthic prey availability. Results from the prey analysis documented significantly lower benthic prey abundance during the fall migratory season compared to the spring, although this could also reflect seasonal fluctuation and reproductive cycles of prey (Colwell 2010). However, with seasonally lower prey availability in the fall and winter seasons, raking of the beach could potentially lower food resources. Dugan et al. (2003) reported that invertebrate density was positively correlated with the density of wrack deposited on the beach, and shorebird density decreased on raked beaches that had lower invertebrate densities. Prey availability data did not show raked beaches significantly reduced invertebrate densities although slightly higher densities of invertebrates were found on unraked beaches. A lack of correlation between benthic prey abundance and raking may be due to less frequent raking and a sampling artifact associated with when benthic samples were collected. For example, Engelhard and Withers (1997) sampled benthic communities on unraked beaches and immediately after raking activity on at Padre Island National Seashore, Texas. They found that beach raking decreased macrofaunal density and biomass and that it took up to 14 days before no significant difference in macrofaunal density was detected at raked and unraked sites. Piping Plovers were observed almost completely avoiding a 190 m stretch of beach that was raked almost every day during the study period. Benthic samples were not collected at this site, yet the data presented by Dugan et al. (2003) and Engelhard and Withers (1997) provides evidence that frequent raking of beaches can greatly reduce prey availability to Piping Plovers.

Seasonal Patterns and Environmental Influences

In this study a decline in Piping Plover abundance was detected through the nonbreeding season on Follets Island, with 41% and 69% less Plovers observed during the winter and spring migratory season respectively in contrast to the fall. This compares with the migratory staging pattern reported in other studies which show a spike in site abundance during migration, particularly in the fall, and decline in the winter (Noel et al. 2007, U.S. Fish and Wildlife Service 2009b, Newstead and Vale 2014). In contrast, Plover densities on Galveston Island remained relatively constant throughout the nonbreeding season. The seasonal decline in Plover abundance recorded on Follets Island compared to Galveston Island may be attributed to greater expanses of available bayside habitat in closer proximity to Follets Island, therefore providing suitable feeding and roosting habitat for extended periods of time during seasonably lower tides or rising and high tides.

The first evidence for this statement is based on a nautical map of the surrounding area (National Oceanic and Atmospheric Administration 2016). The bay systems bordering Follets Island, Christmas and Bastrop Bay, are consistently shallow, approximate average depth of 0.9 m, and consist of a network of uninhabited islands and oyster shell rakes in close proximity to San Luis Pass and between Follets Island and the mainland. Whereas West Bay, bordering Galveston Island, only has a narrow strip of shallow water parallel to the island before dropping to an average depth of 1.5 m, and minimal mid-bayside habitat structures between the island and the mainland (National Oceanic and Atmospheric Administration 2016).

This is supported by results from Newstead and Vale's (2014) radiotelemetry study, conducted concurrently with this study, on winter habitat use of Piping Plovers at the San Luis Pass Inlet and Galveston Island State Park during the winter of 2012-2013. They found that Plovers at the San Luis Pass Inlet were more frequently located feeding and occasionally roosting in tidally-exposed inlet and bayside habitats, such as mudflats and oyster rakes, than on the beach when tide levels were low, whereas Plovers at Galveston Island State Park were most frequently observed on the park beach than in bayside habitats at low tides. They also found that birds radioed on Follets Island, near the inlet, had larger home ranges (2032.2 ha) than birds radioed at Galveston Island State Park (819.9 ha). Newstead and Vale (2014) attribute these findings to a time lag in tide level between the inlet and park which delayed bayside flats from being exposed at the

Park, 20 km from the inlet, by approximately two hours (pers. obs.). Therefore, the shallow bayside habitat may be regularly exposed during a more pronounced diurnal tidal amplitude at San Luis Pass, allowing greater time for Piping Plovers from Follets Island to spend in the bay and less time observed on the beach.

The second evidence for the decline in Plover abundance on Follets Island beaches may also be attributed to increased use of bayside habitats during seasonably lower tide levels that increase exposure time of preferred bayside feeding areas. Tides along the Gulf of Mexico beaches reach their lowest levels in the winter and summer, and highest in the spring and fall (Ward 1997). Furthermore, frequent north winds in the winter push water out of the bay for extended periods of time, thus giving Piping Plovers more opportunities to stay in their preferred habitat. Monthly mean tide levels in this study were significantly lower from January through April (Appendix G), which corresponds closely to the months Plover densities were lowest on Follets Island (Figure 4). This trend is similar with that reported by Haig and Oring (1985) for Piping Plovers at 27 sites across the Gulf States, which showed significantly lower use of beaches from January to March than sand flats adjacent to beaches or coastal inlets. Also in this study Piping Plovers across both islands were observed less during falling tides (Adj. R^2 = 0.068, $P \leq 0.001$, df = 1189), which further suggests they are moving to bayside habitats. This is supported by other studies that observed nonbreeding Piping Plovers shifting and increasing their use in bayside habitats during falling tides or seasonally lower winter tide levels (Zonick 2000, Drake et al. 2001, Cohen al. 2008, Newstead and Vale 2014).

Collectively, adjacent intertidal flats area was independently correlated with mean Piping Plover transect densities across Follets and Galveston Island, showing a significant, yet weak, increase of Piping Plovers with increasing area of intertidal flats. Results from this study are similar to those reported by LeDee (2008) at 31 sites along the Gulf of Mexico coastline (Adj. $R^2 = 0.16$, $P = 0.01$), however are much lower than Zonick's (2000) results ($R^2 = 0.377$, $P = 0.005$) that explained the greatest amount of variability in Plover abundance at his beach and bayside sites along the Texas coastline. Furthermore, Zonick (2000) suggests that barrier island tidal flats were the preferred habitat for Piping Plovers wintering in Texas and sites supporting Piping Plovers must have bayside tidal flats.

The lack of a strong correlation between tidal flat area and patterns in Piping Plover movement during this study may be due to how this habitat area was assessed. Intertidal flats were only measured directly adjacent to each transect within a 1 km x 3.5 km area and not accounting for nearby sites with higher intertidal flats area (i.e., San Luis Pass flats). Through personal observation and results from Newstead and Vale (2014), movements of radioed Piping Plovers were influenced by tidally exposed intertidal flats, often observed in bayside flats diagonal from their beach territory and sometimes at distances greater than 3.5 km.

A slight increase in Piping Plover densities were observed in transects near the San Luis Pass inlet, with significant feeding and roosting clusters identified in transects on both sides of the inlet. Although regression results indicated Piping Plovers increased furthest from the inlet, Plover densities on Follets Island alone were positively correlated with inlet distance (Adj. $R^2 = 0.451$, $P = 0.005$, df = 13). This is consistent with other studies that show an increasing trend in Piping Plover and other shorebird abundance near inlets (Haig and Oring 1985, Nicholls and Baldassarre 1990, Lott et al. 2009).

Newstead and Vale (2014) observed banded Piping Plovers foraging in San Luis Pass flats during low tides and using adjacent beach habitat during high tides when the flats are inundated.

Nonbreeding Piping Plovers have shown preference for polychaete worms over other benthic invertebrate prey groups (Zonick 2000, Cisek 2013). In this study, significantly higher polychaete densities were identified at the inlet benthic site in transect SLP, HHU-2 (Appendix F). These results are similar to Zonick's (2000) who reported 1.5 X higher densities of polychaete in the tidal flats at San Luis Pass than at the adjacent beach. Therefore the observed distribution of Piping Plovers near the San Luis Pass inlet may be influenced by the close proximity to principal foraging areas and a higher abundance of preferred foods.

Significant Plover feeding and roosting clusters identified in beach transects G1, G2, G7, G9 and G10 were in or near beach transects in close proximity to large areas of intertidal bayside flats attributed to constructed marsh mounds. These mounds are made from dredge material for habitat restoration and mitigation projects. The largest areas of created mounds were located on the bayside of transects G2, G4, G5, and G7; G9 had one small area of created mounds. Banded Plovers observed during beach surveys were also located in these intertidal flat areas during Newstead and Vale's (2014) telemetry study. In addition, Newstead and Vale (2014) frequently located Plovers in a newly constructed 288-acre dredge management placement area on Bolivar peninsula. Plover use of intertidal flat habitats created from dredge material is not uncommon. For instance, wintering Piping Plovers at Oregon Inlet, North Carolina, were commonly found on sound islands mostly created islands from dredged-material by the U.S. Army Corps of

Engineers (Cohen et al 2008). Piping Plovers were also reported using newly created or artificial habitat in the breeding range (Haig and Oring 1985). Piping Plover's documented use of created habitat from dredge material indicates this habitat can provide sufficient nonbreeding habitat under the right conditions and influence the utilization of nearby beach habitats.

CONCLUSIONS AND MANAGEMENT RECOMMENDATIONS

Based on the data and analysis from this study it is concluded that the combined influence of beach driving and the anthropogenic influences from development were the most important factors influencing the distribution of Piping Plovers along both islands, while the proximity to large areas of intertidal flats may be a contributing factor in site selection. Given the increasing rate of population growth and development along the Texas coastline, these results can be utilized to help guide future management to reduce disturbance to Piping Plovers and increase habitat quality and site use of important beach habitat. Data from this study suggest that vehicles and beach driving negatively influenced Plover abundance and distribution. Based on these findings, managing vehicular access and beach driving activities along the beach may decrease vehicular disturbance to feeding and roosting Plovers and increase beach habitat quality, management practices that will benefit also benefit other species of imperiled shorebirds. For example, restricting vehicle access by establishing pedestrian only beaches and designated parking areas with bollards can maintain stretches of high quality beach habitat for Plovers while still allowing public access and recreational use of the beach.

Based on study results, Plovers most frequently used lengths of pedestrian beach measuring 2.4 km or more in length. Specific to Follets Island, limiting the 2 km stretch of beach, between transects F1 – F2 adjacent to San Luis Pass, to pedestrian only beach use would protect an important roost site frequented by Piping Plovers.

In May 2013, Brazoria County installed bollards in transect SLP at the San Luis Pass County Park, protecting the western 125 m of inlet beach shoreline from vehicles. Brazoria County later installed more bollards after this study concluded, protecting a total of 500 m of beach. During this study and prior to the installation of bollards at this location, the observed highest Plovers use at SLP was in the fall migratory season; Piping Plovers were not observed in the protected area during the last four surveys when the bollards were installed. A future study comparing Piping Plover use of this site after bollard installation to the pre-installation results from this study would provide insight into the effects of vehicle restriction and other beach driving management activities on Plovers.

Recreational levels (i.e., vehicles, humans, and dogs) during the fall migratory season, the time of peak Plover use of the beach, had a greater influence on Piping Plover distribution than all seasons combined. Therefore, to increase the public awareness of the threatened and endangered Piping Plover, it would be beneficial to install permanent educational signs at vehicle access point, parking area, or other high traffic area of the beach. Signs can informs people of the presence of imperiled species, suggests ways to reduce disturbance to Plovers (e.g., keep dogs on leash), and provide educational and stewardship information to the public.

Results from this study also demonstrated that Plover abundance was negatively correlated with development and positively correlated with bayside tidal flat area. These results suggest that impacts from coastal development to Gulf beaches and intertidal bayside flats should be avoided, minimized, and mitigated to the maximum extent possible. It is important to protect these habitats to support the conservation goals of the Piping Plover Recovery Plan (U.S. Fish and Wildlife Service 2015).

This study indicated unraked beaches were preferred habitat features for roosting Plovers and seasonally raked beaches were used by feeding and roosting Plovers. Accordingly, beach management practices that can enhance Piping Plover habitat quality include avoiding or reducing the frequency of beach raking at important sites utilized by Piping Plovers. Additionally, leaving beaches mostly unraked in the winter or other periods of low recreational beach use, may also improve beach habitat quality for Piping Plovers, and other shorebirds, while balancing the desire to maintain the beach for esthetics and recreational use.

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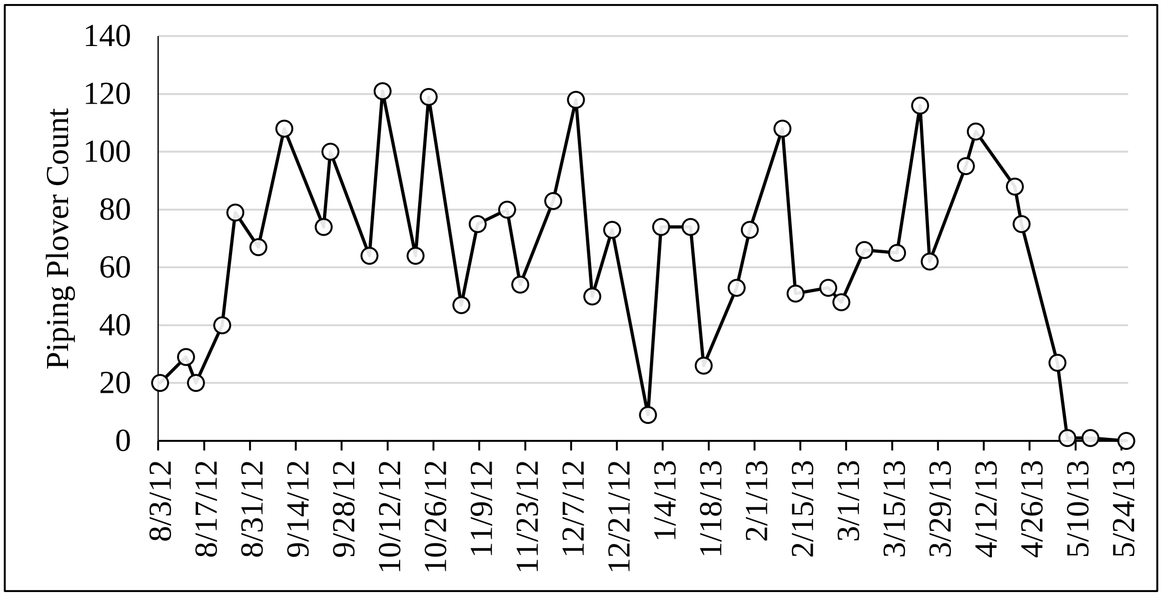
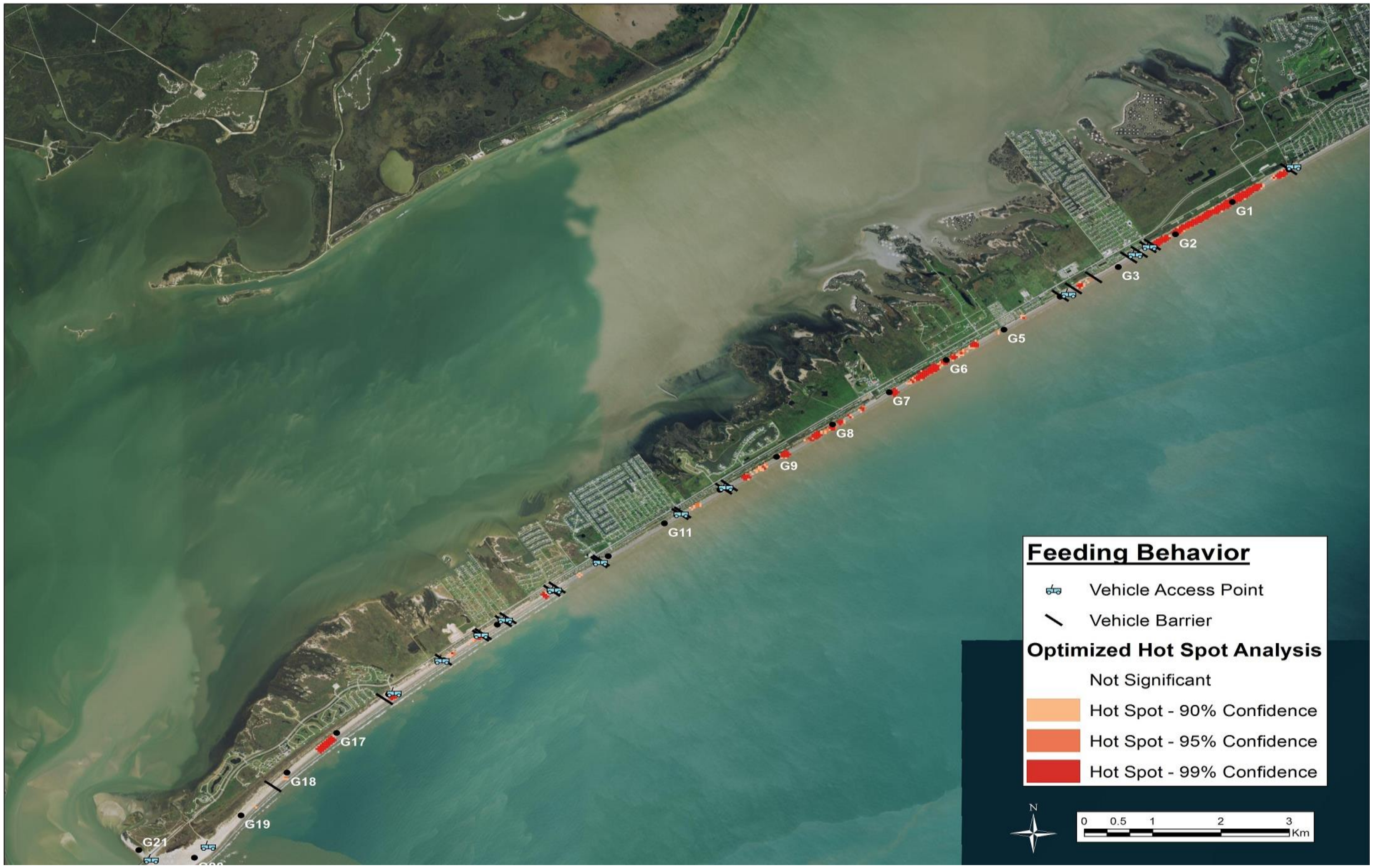
APPENDIX

Appendix A. Total survey counts of Piping Plovers pooled across Follets Island and Galveston Island from 3 Aug 2012 to 25 May 2013 (*n* = 43).



Appendix B-1. Optimized hot spot analysis results showing significant feeding clusters on Galveston Island. Data based on feeding observations (*n* = 2014) from 26 Aug 2012 – 23 Apr 2013 surveys (*n* = 35).

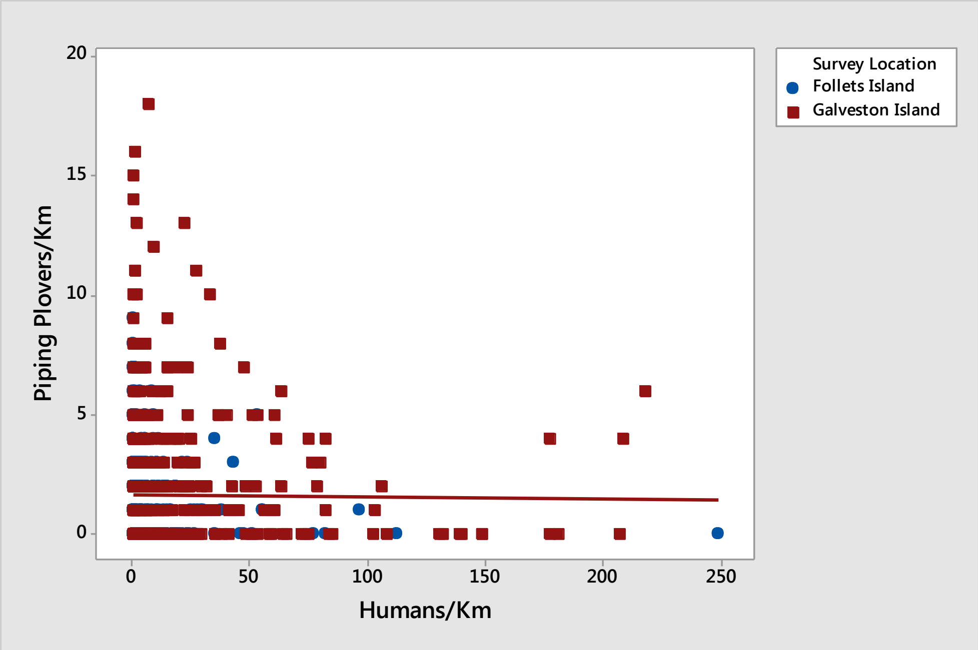


Appendix B-2. Optimized hot spot analysis results showing significant roosting clusters on Galveston Island. Data based on roosting observations (*n* = 600) from 26 Aug 2012 – 23 Apr 2013 surveys (*n* = 35).

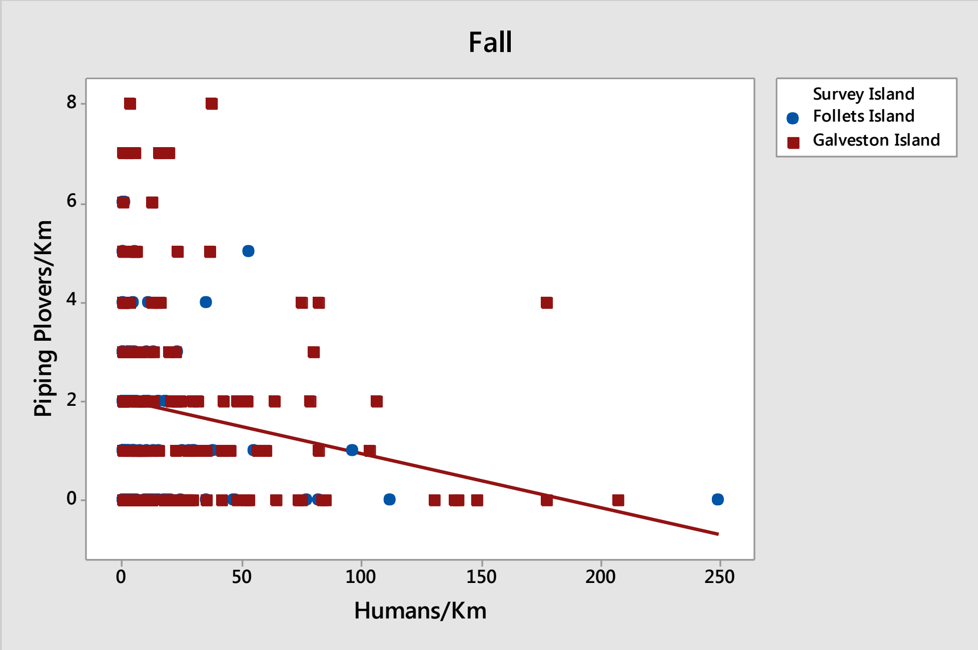
Appendix B-3. Optimized hot spot analysis results showing significant feeding clusters on Follets Island. Data based on feeding observations (*n* = 2014) from 26 Aug 2012 – 23 Apr 2013 surveys (*n* = 35).

Appendix B-4. Optimized hot spot analysis results showing significant roosting clusters on Galveston Island. Data based on roosting observations (*n* = 600) from 26 Aug 2012 – 23 Apr 2013 surveys (*n* = 35).

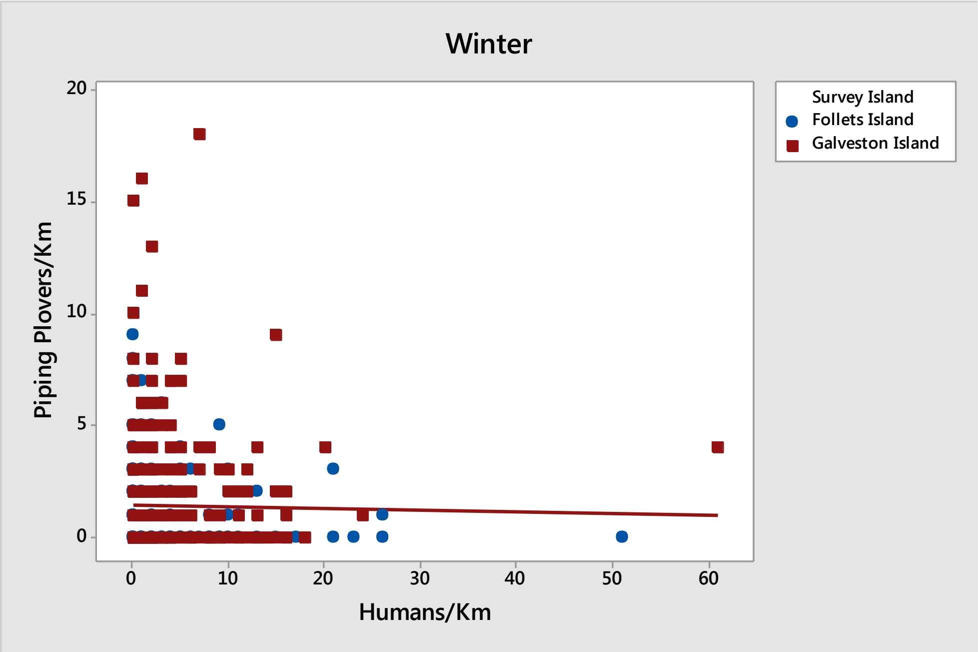
Appendix C-1. Scatterplot showing the relationship between densities of feeding Piping Plovers and humans from linear beach transects across Follets Island and Galveston Island (*n* = 34). Data from 26 August 2012 – 23 April 2013 surveys (*n* = 35). Simple linear regression fitted line (Adj. $R^2 \leq 0.001$, $P = 0.732$, df = 1189).



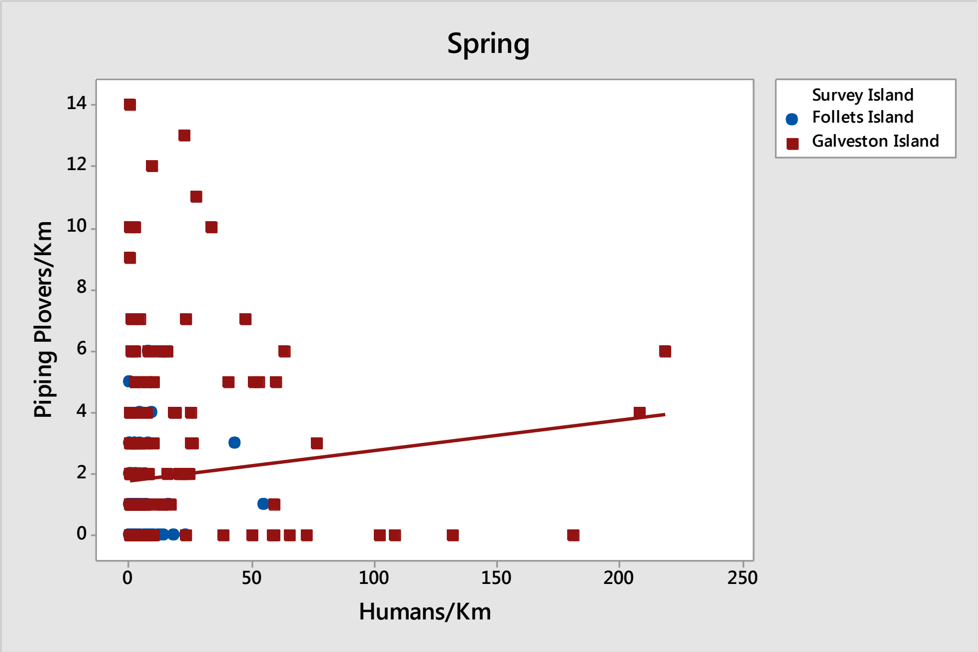
Appendix C-2. Scatterplot showing the relationship between fall densities of feeding Piping Plovers and humans from linear beach transects across Follets Island and Galveston Island (*n* = 34). Data from 26 Aug 2012 – 24 Oct 2012 surveys (*n* = 9). Simple linear regression fitted line (Adj. $R^2 = 0.040$, $P \leq 0.001$, df = 305).



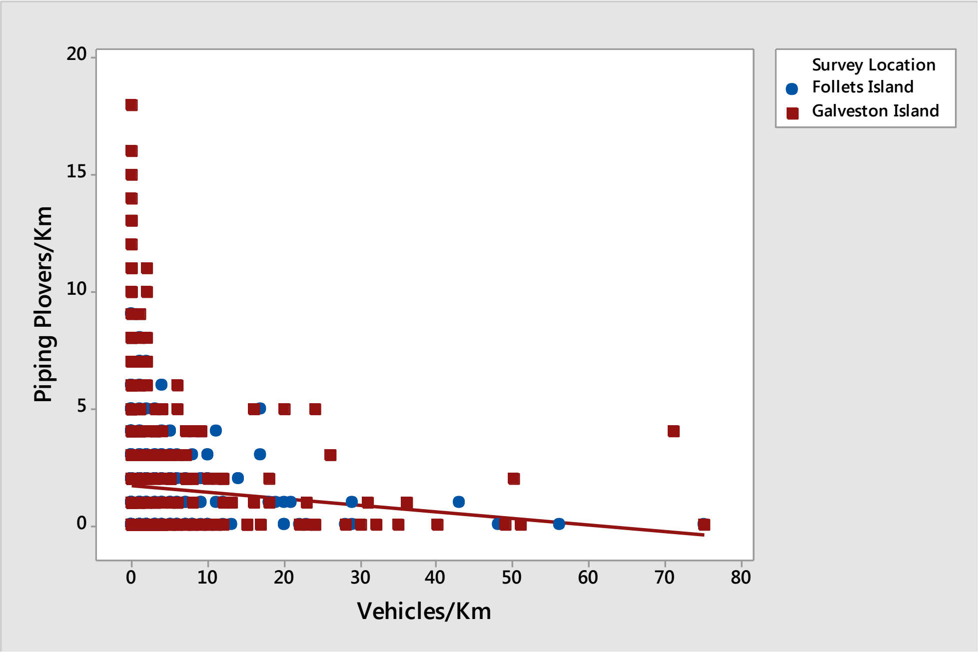
Appendix C-3. Scatterplot showing the relationship between winter densities of feeding Piping Plovers and humans from linear beach transects across Follets Island and Galveston Island ($n = 34$). Data from 3 Nov 2012 – 27 Feb 2013 surveys ($n = 18$). Simple linear regression fitted line (Adj. $R^2 \leq 0.001$, $P = 0.639$, df = 611).



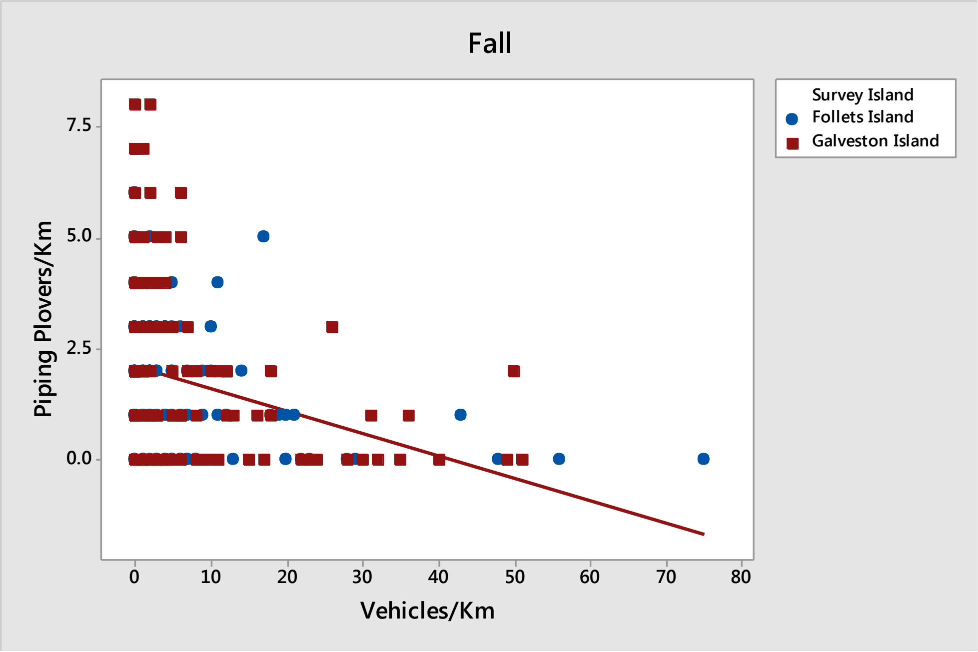
Appendix C-4. Scatterplot showing the relationship between winter densities of feeding Piping Plovers and humans from linear beach transects across Follets Island and Galveston Island ($n = 34$). Data from 6 Mar 2013 – 23 Apr 2013 surveys ($n = 8$). Simple linear regression fitted line (Adj. $R^2 = 0.008$, $P = 0.078$, df = 271).



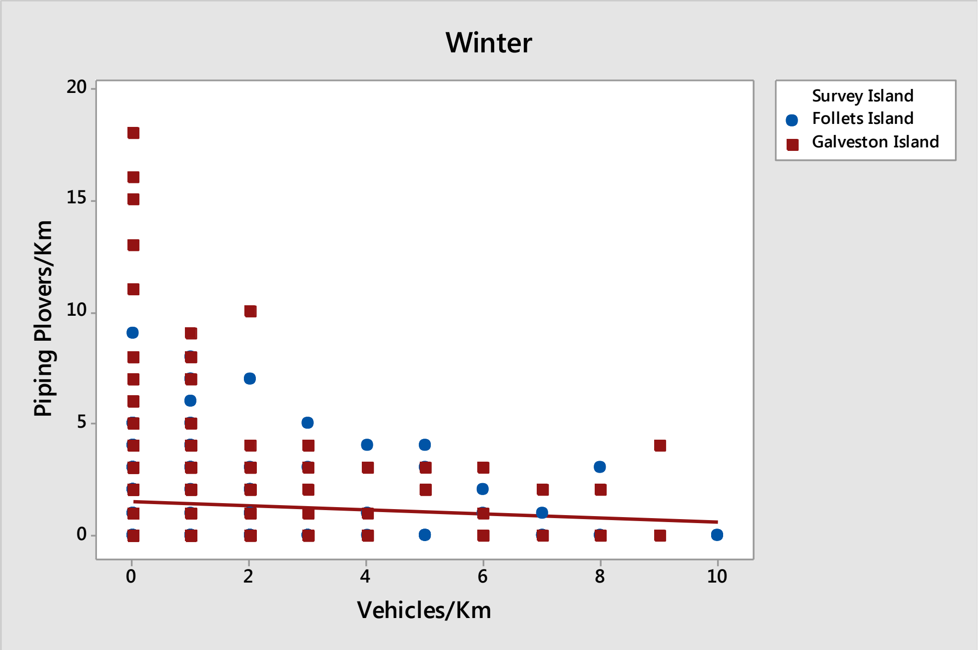
Appendix C-5. Scatterplot showing the relationship between densities of feeding Piping Plovers and vehicles from linear beach transects across Follets Island and Galveston Island (*n* = 34). Data from 26 Aug 2012 – 23 Apr 2013 surveys (*n* = 35). Simple linear regression fitted line (Adj. $R^2 = 0.028$, $P = 0.006$, df = 1189).



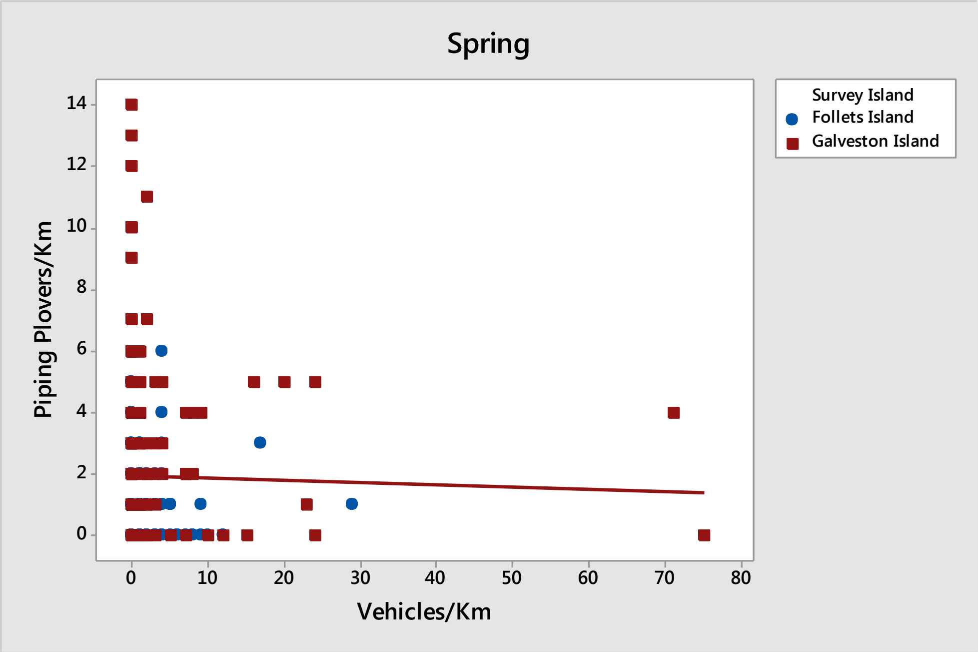
Appendix C-6. Scatterplot showing the relationship between fall densities of feeding Piping Plovers and vehicles from linear beach transects across Follets Island and Galveston Island (*n* = 34). Data from 26 Aug 2012 – 24 Oct 2012 surveys (*n* = 9). Simple linear regression fitted line (Adj. $R^2 = 0.081$, $P \leq 0.001$, df = 305).



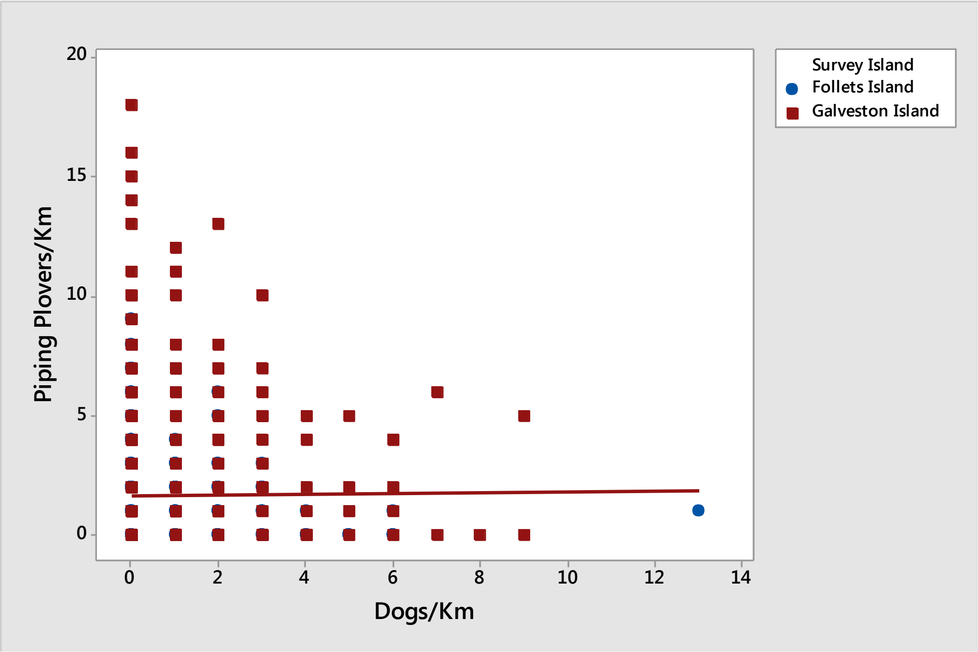
Appendix C-7. Scatterplot showing the relationship between winter densities of feeding Piping Plovers and vehicles from linear beach transects across Follets Island and Galveston Island (*n* = 34). Data from 3 Nov 2012 – 27 Feb 2013 surveys (*n* = 18). Simple linear regression fitted line (Adj. $R^2 = 0.002$, $P = 0.115$, df = 611).



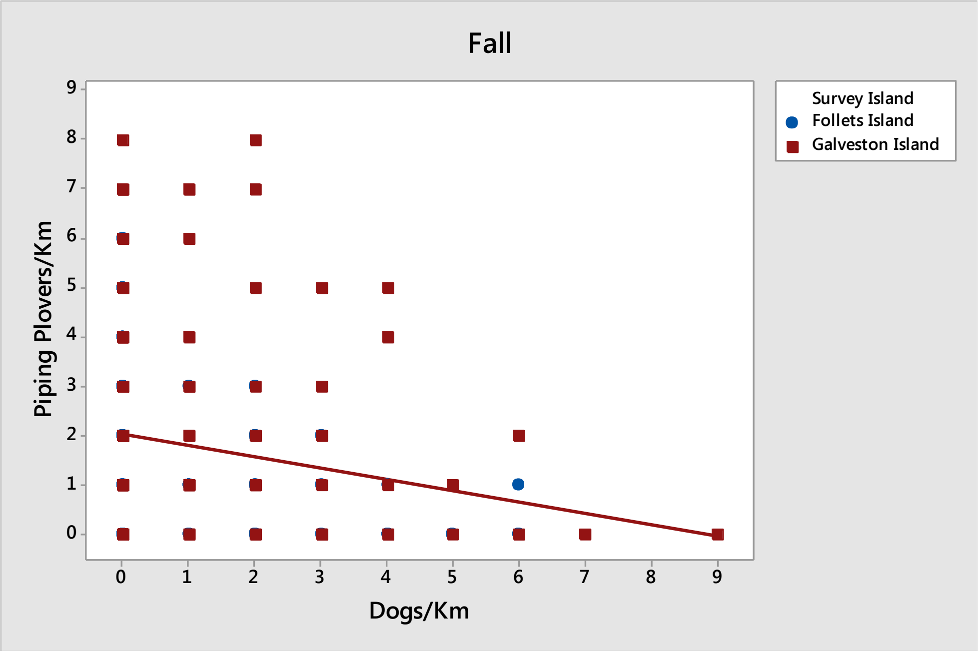
Appendix C-8. Scatterplot showing the relationship between winter densities of feeding Piping Plovers and vehicles from linear beach transects across Follets Island and Galveston Island (*n* = 34). Data from 6 Mar 2013 – 23 Apr 2013 surveys (*n* = 8). Simple linear regression fitted line (Adj. $R^2 = 0.000$, $P = 0.718$, df = 271).



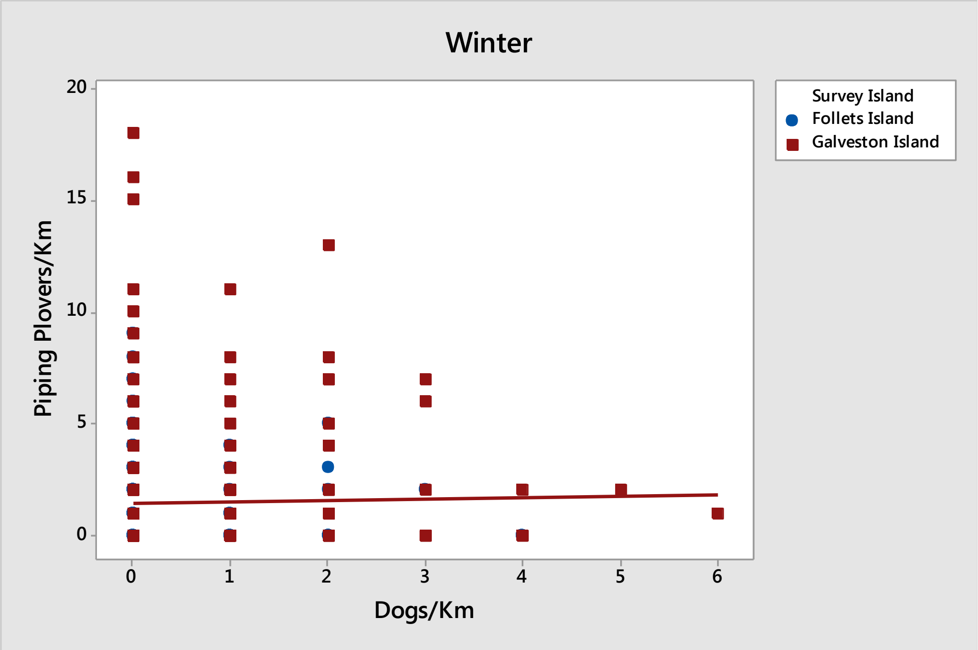
Appendix C-9. Scatterplot showing the relationship between densities of feeding Piping Plovers and dogs from linear beach transects across Follets Island and Galveston Island (*n* = 34). Data from 26 August 2012 – 23 April 2013 surveys (*n* = 35). Simple linear regression fitted line (Adj. $R^2 \leq 0.001$, $P = 0.753$, df = 1189).



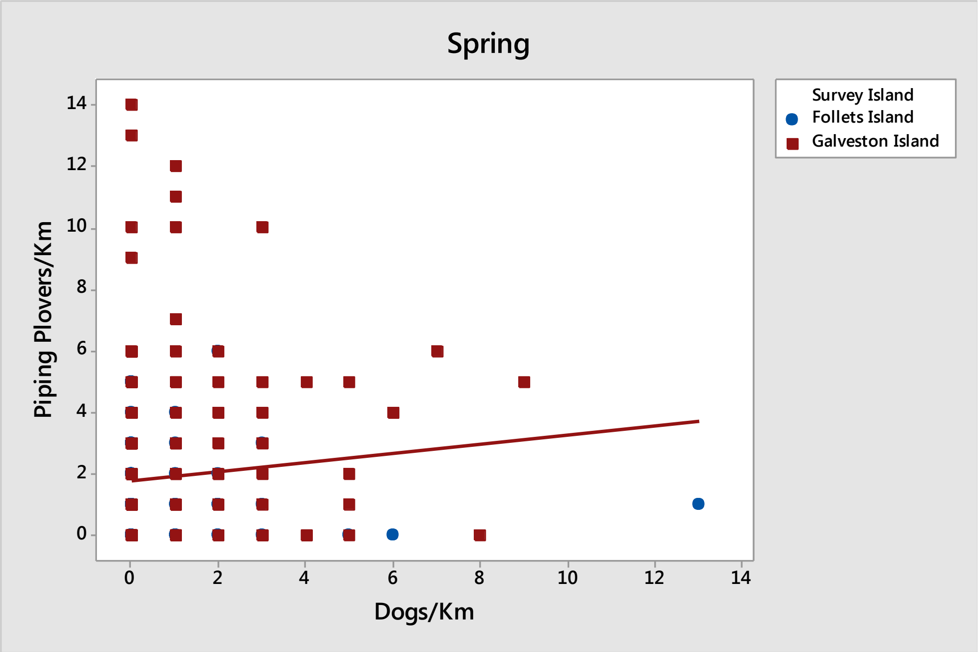
Appendix C-10. Scatterplot showing the relationship between fall densities of feeding Piping Plovers and dogs from linear beach transects across Follets Island and Galveston Island (*n* = 34). Data from 26 Aug 2012 – 24 Oct 2012 surveys (*n* = 9). Simple linear regression fitted line (Adj. $R^2 = 0.037$, $P \leq 0.001$, df = 305).



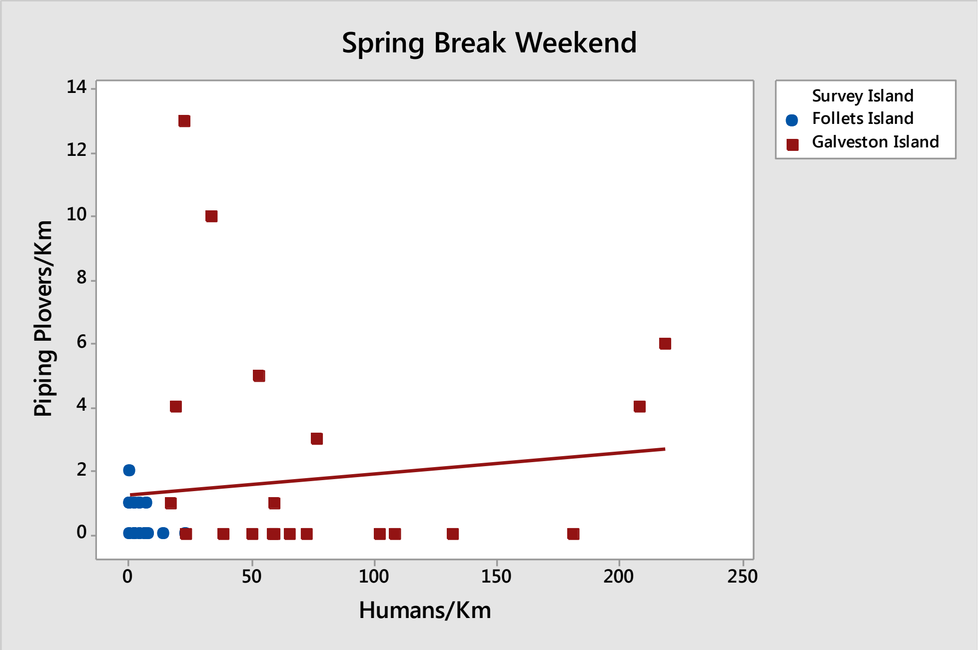
Appendix C-11. Scatterplot showing the relationship between winter densities of feeding Piping Plovers and dogs from linear beach transects across Follets Island and Galveston Island (*n* = 34). Data from 3 Nov 2012 – 27 Feb 2013 surveys (*n* = 18). Simple linear regression fitted line (Adj. $R^2 \leq 0.001$, $P = 0.516$, df = 611).



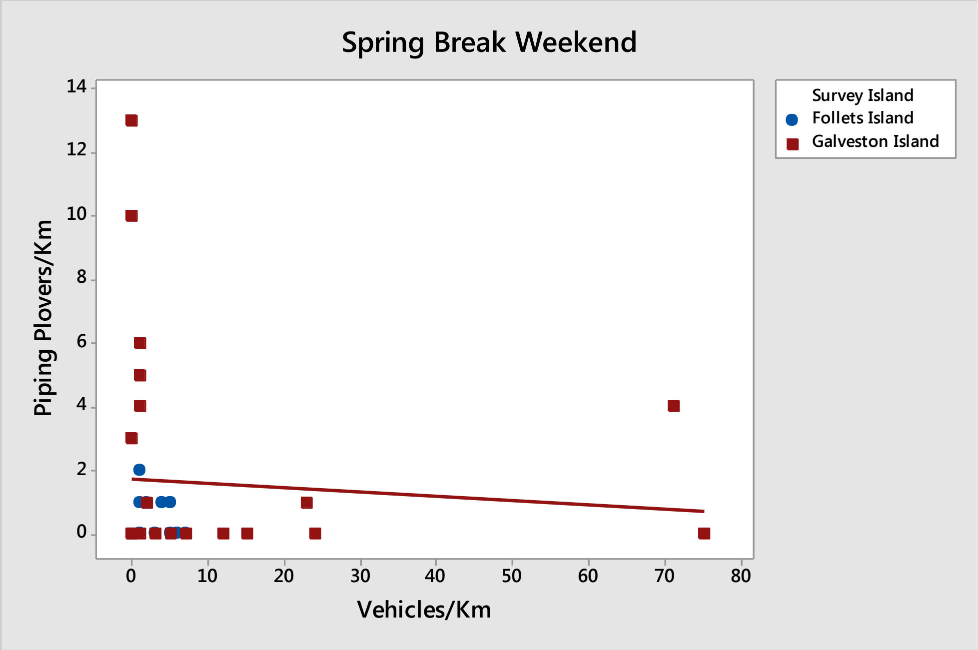
Appendix C-12. Scatterplot showing the relationship between winter densities of feeding Piping Plovers and dogs from linear beach transects across Follets Island and Galveston Island (*n* = 34). Data from 6 Mar 2013 – 23 Apr 2013 surveys (*n* = 8). Simple linear regression fitted line (Adj. $R^2 = 0.004$, $P = 0.115$, df = 271).



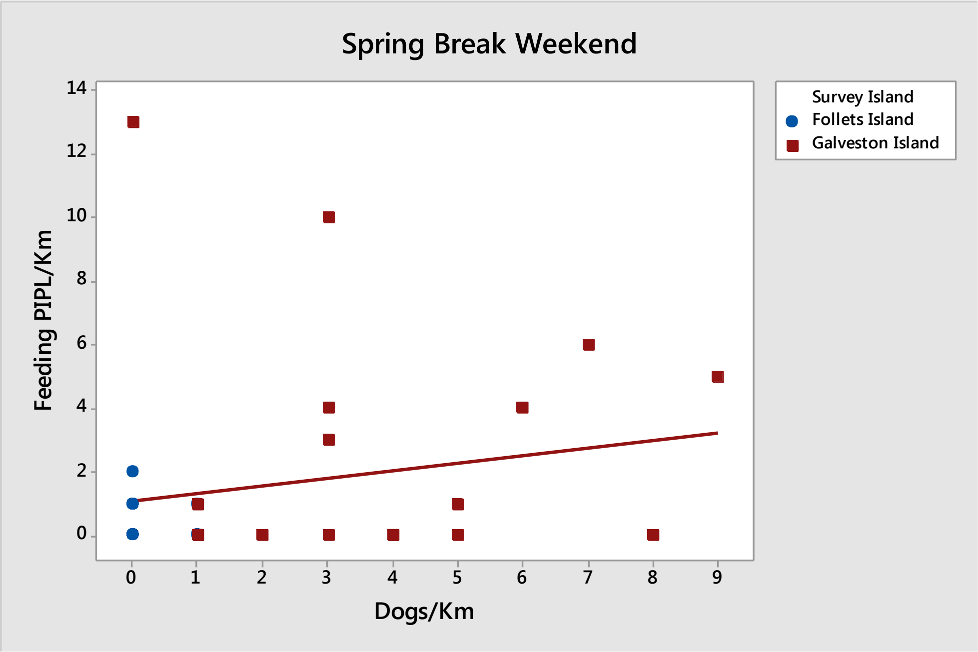
Appendix D-1. Scatterplot showing the relationship between densities of feeding Piping Plovers and humans during the Spring Break weekend survey on 16 March 2013 across Follets Island and Galveston Island ($n = 34$). Simple linear regression fitted line (Adj. $R^2 = 0.001$, $P = 0.462$, df = 33).



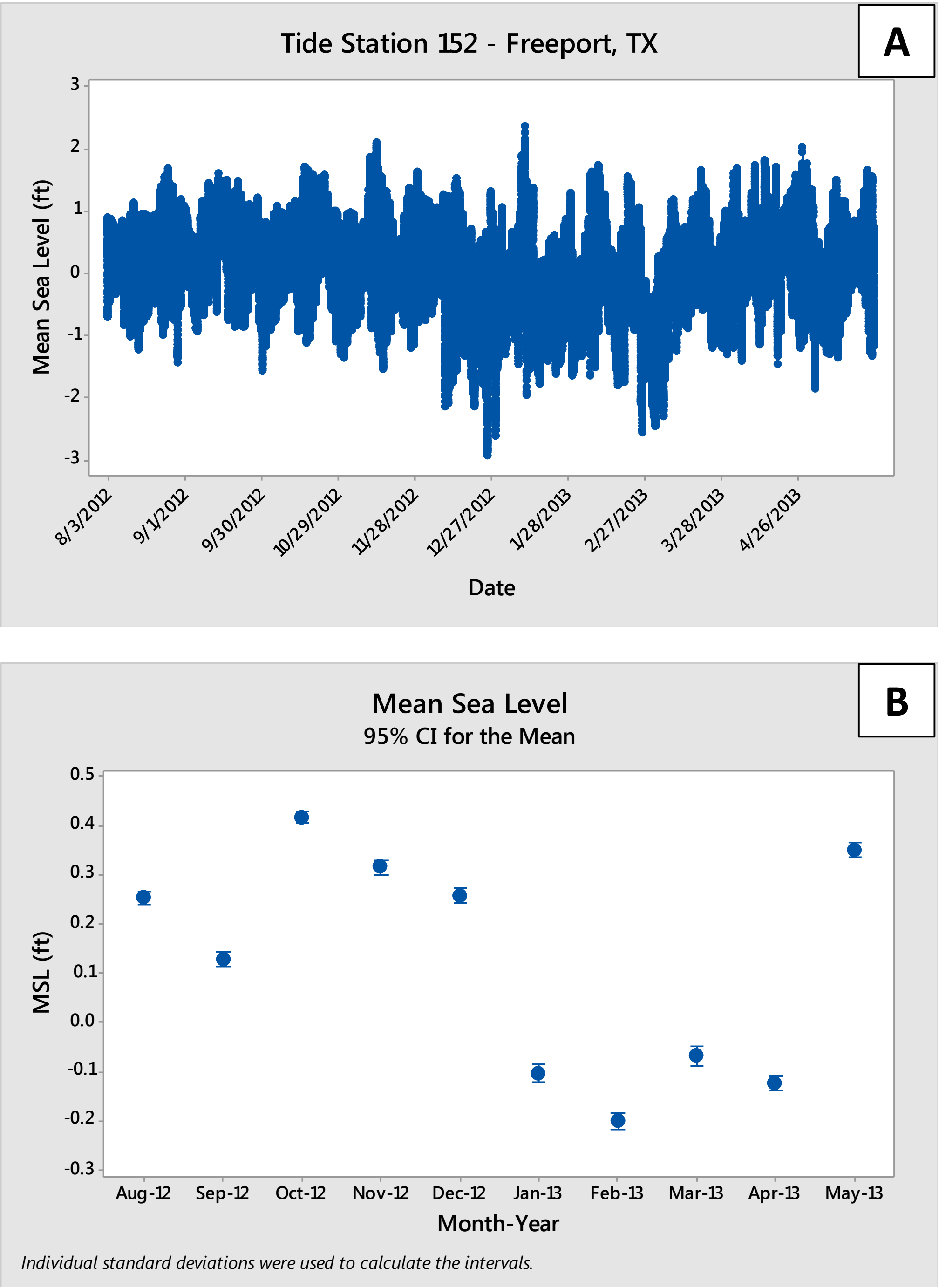
Appendix D-2. Scatterplot showing the relationship between densities of feeding Piping Plovers and vehicles during the Spring Break weekend survey on 16 March 2013 across Follets Island and Galveston Island ($n = 34$). Simple linear regression fitted line (Adj. $R^2 = 0.001$, $P = 0.665$, df = 33).



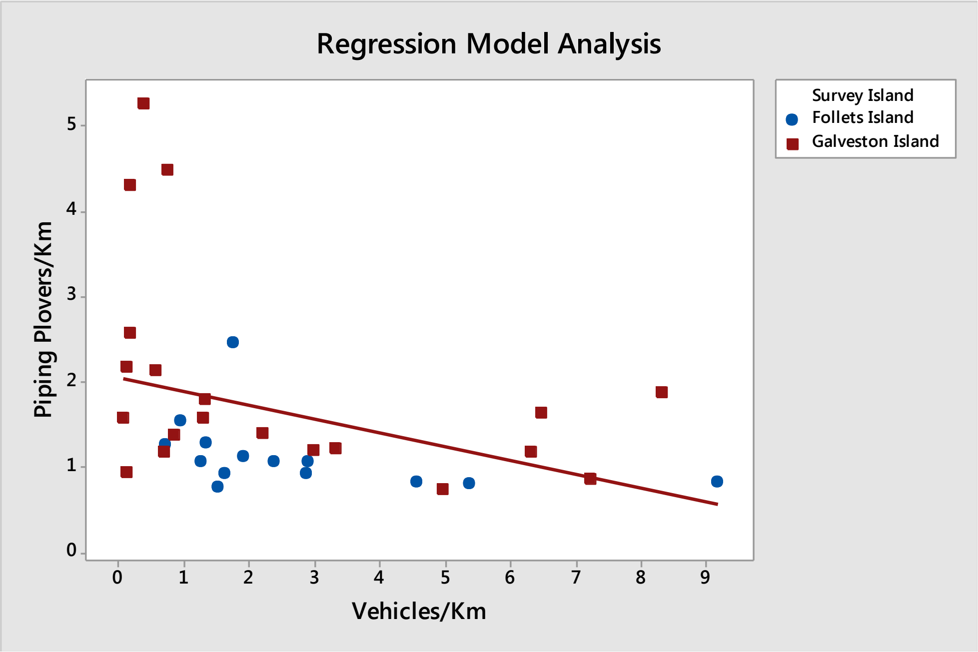
Appendix D-3. Scatterplot showing the relationship between feeding Piping Plover and dog densities during the Spring Break weekend survey on 16 March 2013 across Follets Island and Galveston Island (*n* = 34). Simple linear regression fitted line (Adj. R^2 = 0.001, $P = 0.247$, df = 33).



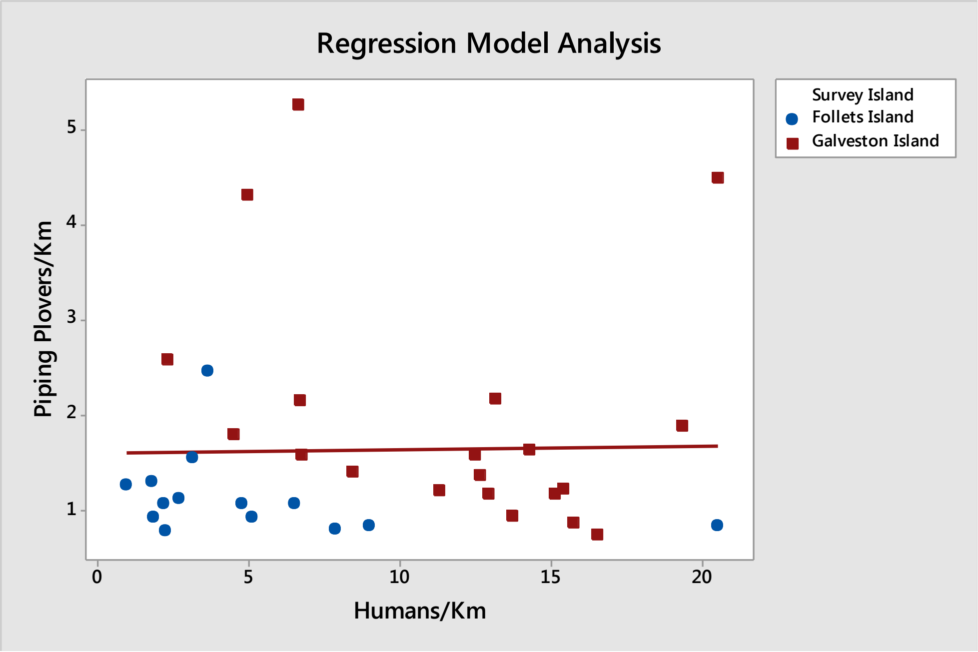
Appendix E. Daily (A) and monthly (B) mean sea level data extracted from TCOON tide station 152 located in Freeport, TX. Data based on 6-minute station collection intervals during the extent of this study from 3 Aug 2012 – 25 May 2013.



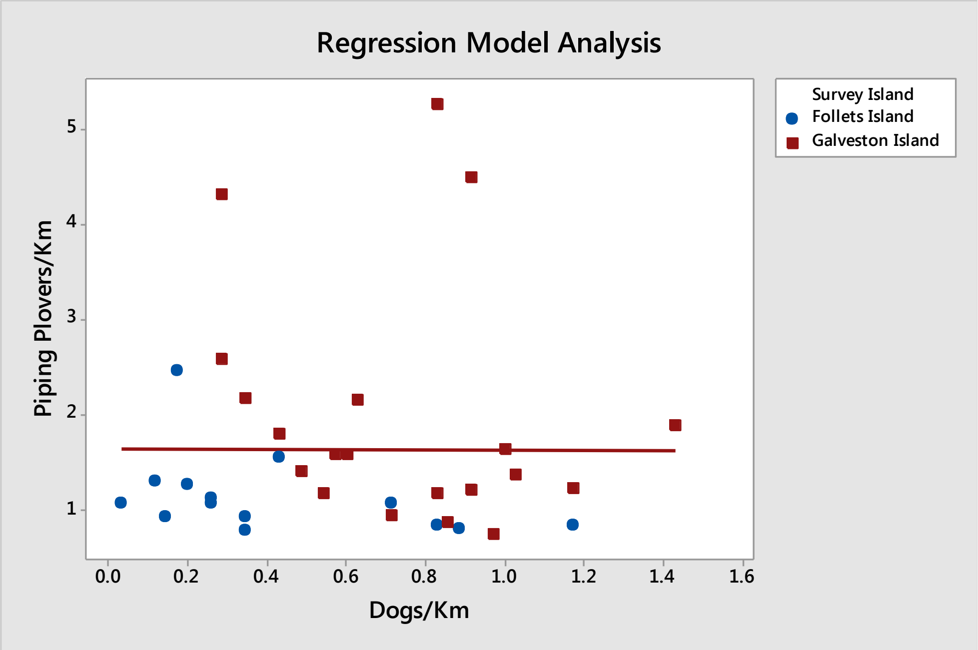
Appendix F-1. Scatterplot showing the relationship between mean densities of feeding Piping Plovers and vehicles per linear beach transects across Follets Island and Galveston Island (*n* = 34). Data from 26 August 2012 – 23 April 2013 surveys (*n* = 35). Simple linear regression fitted line (Adj. $R^2 = 0.114$, $P = 0.029$, df = 33).



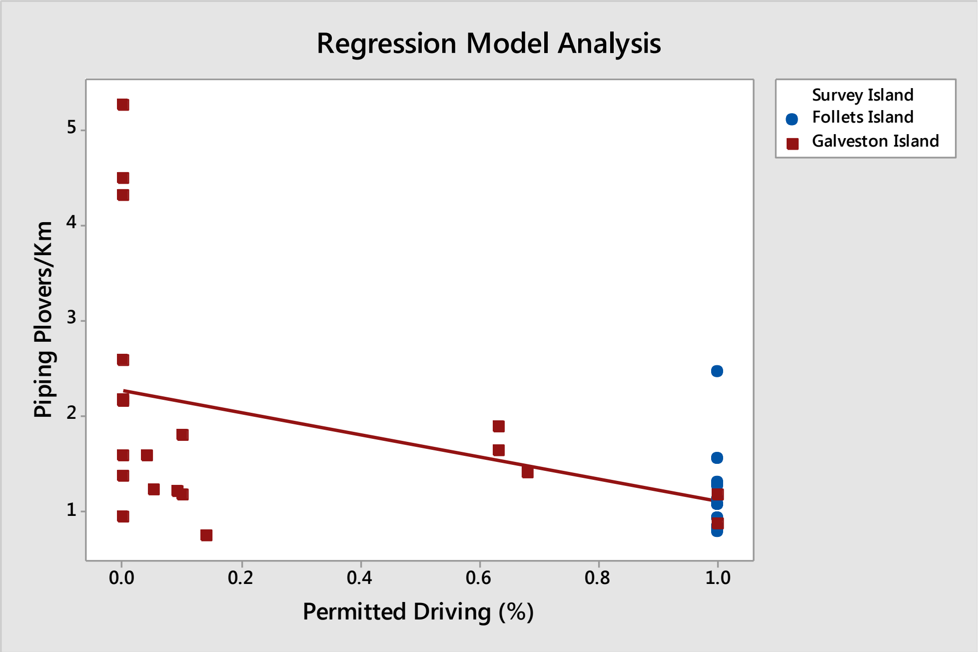
Appendix F-2. Scatterplot showing the relationship between mean densities of feeding Piping Plovers and humans per linear beach transects across Follets Island and Galveston Island (*n* = 34). Data from 26 August 2012 – 23 April 2013 surveys (*n* = 35). Simple linear regression fitted line (Adj. $R^2 \leq 0.001$, $P = 0.920$, df = 33).



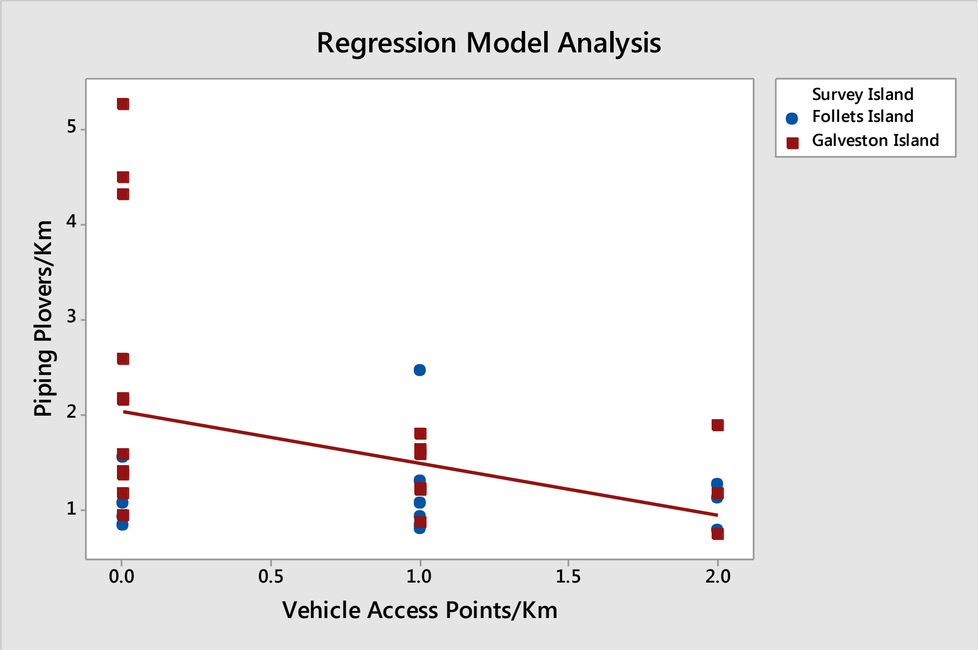
Appendix F-3. Scatterplot showing the relationship between mean densities of feeding Piping Plovers and dog per linear beach transects across Follets Island and Galveston Island (*n* = 34). Data from 26 August 2012 – 23 April 2013 surveys (*n* = 35). Simple linear regression fitted line (Adj. $R^2 \leq 0.001$, $P = 0.992$, df = 33).



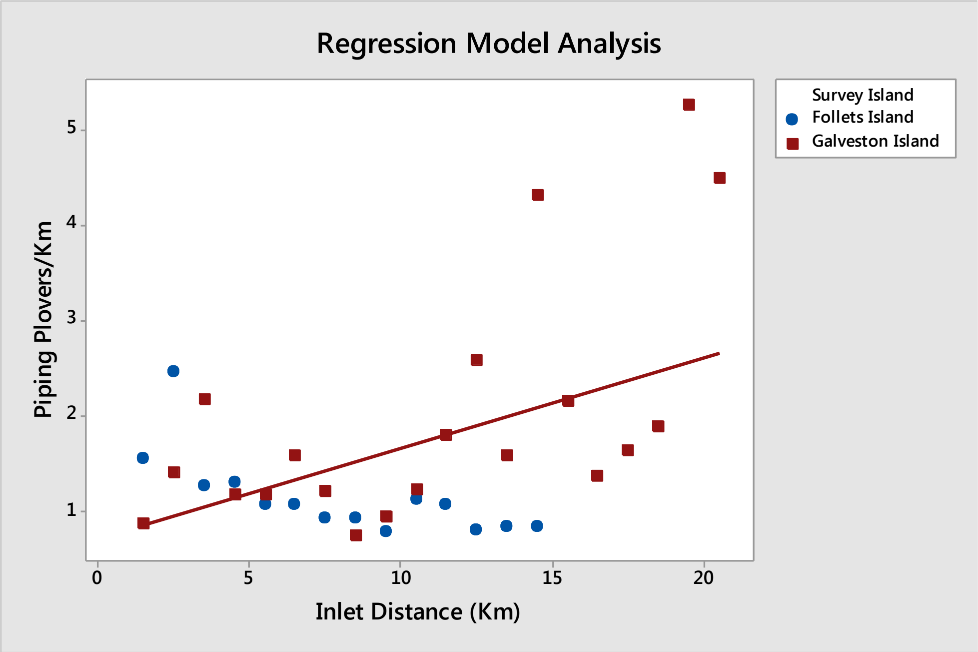
Appendix F-4. Scatterplot showing the relationship between mean densities of feeding Piping Plovers and permitted driving per linear beach transects across Follets Island and Galveston Island (*n* = 34). Data from 26 August 2012 – 23 April 2013 surveys (*n* = 35). Simple linear regression fitted line (Adj. $R^2 = 0.224$, $P = 0.003$, df = 33).



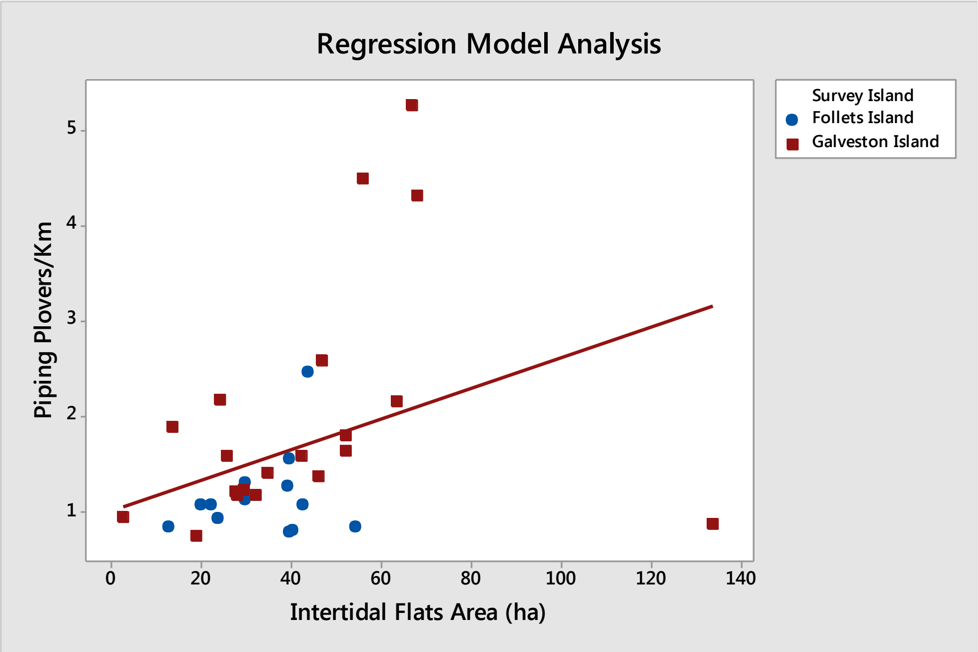
Appendix F-5. Scatterplot showing the relationship between mean densities of feeding Piping Plovers and vehicle access points per linear beach transects across Follets Island and Galveston Island (*n* = 34). Data from 26 August 2012 – 23 April 2013 surveys (*n* = 35). Simple linear regression fitted line (Adj. $R^2 = 0.116$, $P = 0.028$, df = 33).



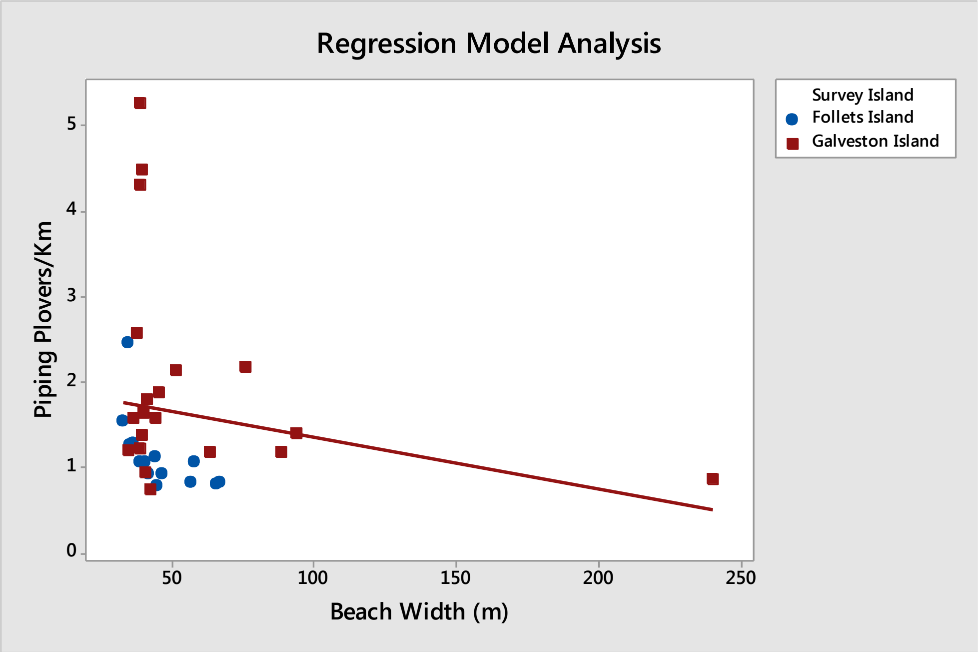
Appendix F-6. Scatterplot showing the relationship between mean densities of feeding Piping Plovers and inlet distance per linear beach transects across Follets Island and Galveston Island (*n* = 34). Data from 26 August 2012 – 23 April 2013 surveys (*n* = 35). Simple linear regression fitted line (Adj. $R^2 = 0.089$, $P = 0.048$, df = 33).



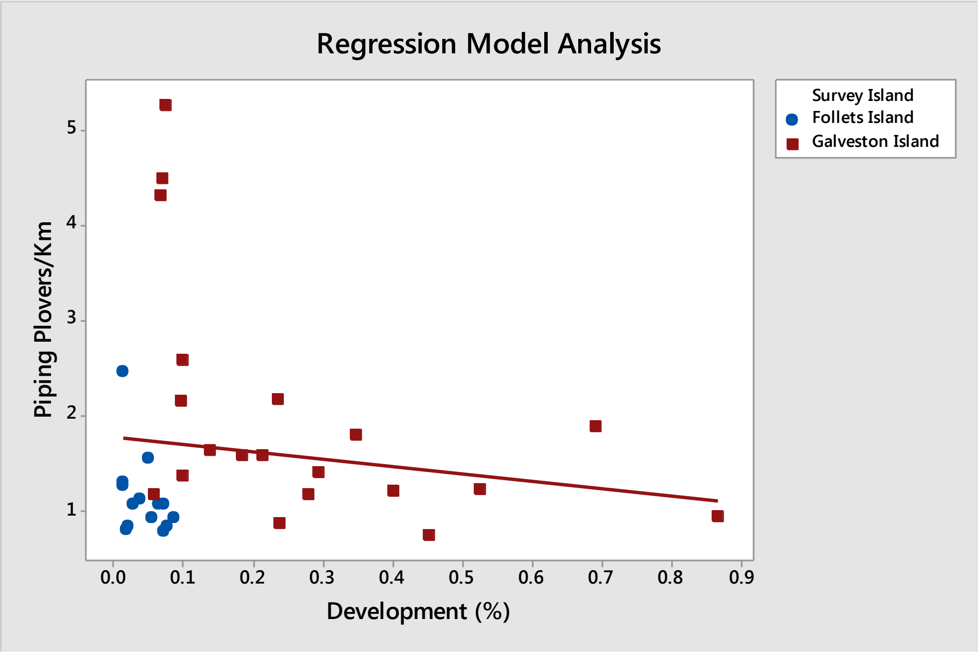
Appendix F-7. Scatterplot showing the relationship between mean densities of feeding Piping Plovers and intertidal flats area per linear beach transects across Follets Island and Galveston Island (*n* = 34). Data from 26 August 2012 – 23 April 2013 surveys (*n* = 35). Simple linear regression fitted line (Adj. $R^2 = 0.089$, $P = 0.048$, df = 33).



Appendix F-8. Scatterplot showing the relationship between mean densities of feeding Piping Plovers and mean beach width per linear beach transects across Follets Island and Galveston Island (*n* = 34). Data from 26 August 2012 – 23 April 2013 surveys (*n* = 35). Simple linear regression fitted line (Adj. $R^2 = 0.011$, $P = 0.248$, df = 33).



Appendix F-9. Scatterplot showing the relationship between mean densities of feeding Piping Plovers and development per linear beach transects across Follets Island and Galveston Island (*n* = 34). Data from 26 August 2012 – 23 April 2013 surveys (*n* = 35). Simple linear regression fitted line (Adj. $R^2 \leq 0.001$, $P = 0.415$, df = 33).



Appendix G. Spearman rank-order correlation coefficients between independent continuous and discrete variables used to build the multiple regression model from linear beach transects from 26 August 2012 – 23 April 2013 surveys (*n* = 34).

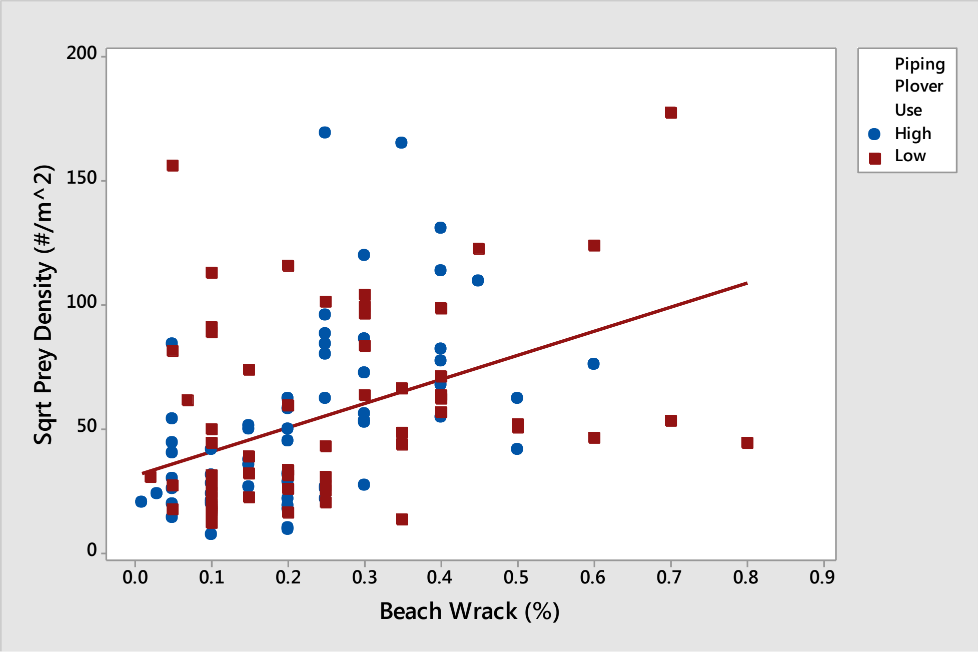
Variable 1	Variable 2	Spearman Correlation	P value
Mean Vehicles/km	Mean Humans/km	0.319	0.066
Mean Dogs/km	Mean Humans/km	0.851	0.000
Developed Land (%)	Mean Humans/km	0.610	0.000
Permitted Driving (%)	Mean Humans/km	-0.369	0.032
Vehicle Access Points (#/km)	Mean Humans/km	-0.009	0.961
Intertidal Flats Area (ha)	Mean Humans/km	0.010	0.956
Mean Beach Width (m)	Mean Humans/km	0.411	0.016
Inlet Distance (km)	Mean Humans/km	0.303	0.082
Mean Dogs/km	Mean Vehicles/km	0.458	0.006
Developed Land (%)	Mean Vehicles/km	0.000	0.999
Permitted Driving (%)	Mean Vehicles/km	0.609	0.000
Vehicle Access Points (#/km)	Mean Vehicles/km	0.631	0.000
Intertidal Flats Area (ha)	Mean Vehicles/km	-0.144	0.417
Mean Beach Width (m)	Mean Vehicles/km	0.412	0.015
Inlet Distance (km)	Mean Vehicles/km	-0.019	0.914
Developed Land (%)	Mean Dogs/km	0.495	0.003
Permitted Driving (%)	Mean Dogs/km	-0.293	0.092
Vehicle Access Points (#/km)	Mean Dogs/km	0.127	0.474
Intertidal Flats Area (ha)	Mean Dogs/km	0.129	0.465
Mean Beach Width (m)	Mean Dogs/km	0.276	0.114
Inlet Distance (km)	Mean Dogs/km	0.508	0.002
Permitted Driving (%)	Developed Land (%)	-0.580	0.000
Vehicle Access Points (#/km)	Developed Land (%)	-0.064	0.717
Intertidal Flats Area (ha)	Developed Land (%)	-0.173	0.327
Mean Beach Width (m)	Developed Land (%)	0.178	0.313
Inlet Distance (km)	Developed Land (%)	0.109	0.539
Vehicle Access Points (#/km)	Permitted Driving (%)	0.505	0.002
Intertidal Flats Area (ha)	Permitted Driving (%)	-0.220	0.212
Mean Beach Width (m)	Permitted Driving (%)	0.204	0.247
Inlet Distance (km)	Permitted Driving (%)	-0.456	0.007
Intertidal Flats Area (ha)	Vehicle Access Points (#/km)	-0.151	0.395
Mean Beach Width (m)	Vehicle Access Points (#/km)	0.137	0.438
Inlet Distance (km)	Vehicle Access Points (#/km)	-0.138	0.437
Mean Beach Width (m)	Intertidal Flats Area (ha)	-0.095	0.592
Inlet Distance (km)	Intertidal Flats Area (ha)	0.315	0.069
Inlet Distance (km)	Mean Beach Width (m)	-0.044	0.805

Appendix H. Mean benthic density (m^2) and relative sample density (RD) for select invertebrate groups identified at sample sites across Follets Island and Galveston Island from 19 October 2012 to 20 May 2013 (*n* = 8). Planktonic invertebrates were identified in 35 samples and included the total prey.

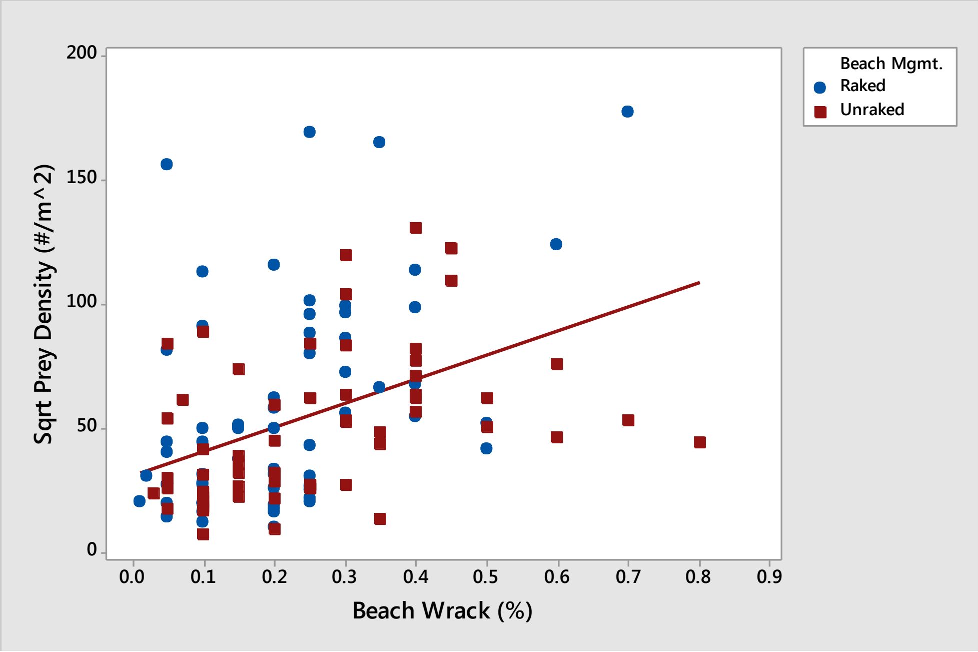
			Polychaete			Amphipod			Isopod			Bivalve			Total Prey	
Site	Km	*n*	$\bar{x}$	SE	*RD*	$\bar{x}$	SE	*RD*	$\bar{x}$	SE	*RD*	$\bar{x}$	SE	*RD*	$\bar{x}$	SE
HHR-1[a]	G10	7	53	18.73	0.01	6312	3486.28	0.95	97	85.78	0.01	45	26.57	0.01	6659	3623.03
HHR-2	F5	8	42	25.10	0.01	4567	3438.35	0.96	6	5.85	0.00	9	7.25	0.00	4773	3426.13
HHU-1	G4	7	82	46.50	0.04	2035	1514.27	0.87	25	25.06	0.01	38	25.23	0.02	2334	1614.05
HHU-2	SLP	7	1357	955.02	0.71	214	125.30	0.11	0	0.00	0.00	2	1.67	0.00	1905	914.21
HLR-1	G7	7	85	34.68	0.03	3124	1194.95	0.93	2	1.67	0.00	30	28.17	0.01	3368	1186.52
HLR-2	F1	8	45	17.60	0.01	3646	1518.98	0.91	3	1.91	0.00	22	15.54	0.01	3991	1455.41
HLU-1	G9	8	60	19.20	0.02	2529	1002.59	0.91	7	5.82	0.00	28	16.08	0.01	2792	1002.06
HLU-2	F2	7	18	8.41	0.00	6137	2549.83	0.98	0	0.00	0.00	7	4.31	0.00	6282	2535.74
HLU	G1	3	168	70.28	0.05	3185	1273.02	0.90	4	3.90	0.00	27	14.06	0.01	3551	1202.11
LHR-1	G13	7	32	10.43	0.00	5031	1828.28	0.62	190	190.46	0.02	35	21.20	0.00	8121	4173.65
LHR-2	G14	8	85	31.70	0.02	4684	2002.95	0.88	159	146.44	0.03	12	5.41	0.00	5317	2251.03
LHU-1	G21	8	19	15.77	0.01	2494	1028.38	0.98	1	1.46	0.00	10	6.03	0.00	2555	1013.43
LHU-2	F12	7	7	2.36	0.00	2855	1390.70	0.97	0	0.00	0.00	3	2.16	0.00	2952	1375.07
LLR-1	G5	7	107	50.17	0.04	2556	1242.10	0.93	17	16.71	0.01	23	11.12	0.01	2758	1237.98
LLR-2	G19	8	16	6.23	0.00	6459	2990.93	0.95	120	118.21	0.02	12	5.41	0.00	6790	2993.50
LLU-1	F4	7	47	30.94	0.01	4053	1990.25	0.90	2	1.67	0.00	7	5.01	0.00	4493	1908.95
LLU-2	F9	8	76	49.22	0.03	2133	697.34	0.84	1	1.46	0.00	28	17.67	0.01	2552	630.11

[a] HHR = High Piping Plovers, High recreational Use, Raked beach

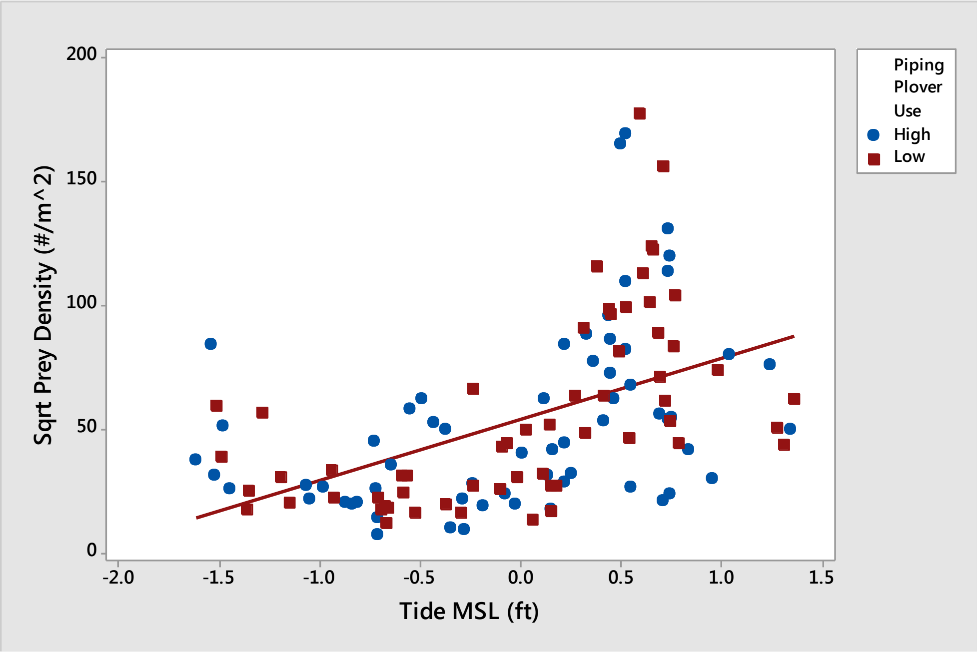
Appendix I-1. Scatterplot of the square root transformed benthic organism density versus percent beach wrack represented by Piping Plover use. Data from survey sites across Follets Island and Galveston Island from 19 October 2012 to 20 May 2013 (*n* = 8). Simple linear regression fitted line (Adj. $R^2 = 0.166$, $P \leq 0.001$, df = 121).



Appendix I-2. Scatterplot of the square root transformed benthic organism density versus percent beach wrack represented by beach raking management. Data from survey sites across Follets Island and Galveston Island from 19 October 2012 to 20 May 2013 (*n* = 8). Simple linear regression fitted line (Adj. $R^2 = 0.166$, $P \leq 0.001$, df = 121).



Appendix I-3. Scatterplot of the square root transformed benthic organism density versus tide level represented by Piping Plover use. Data from survey sites across Follets Island and Galveston Island from 19 October 2012 to 20 May 2013 ($n = 8$). Simple linear regression fitted line (Adj. $R^2 = 0.239$, $P \leq 0.001$, df = 121).



Appendix I-4. Scatterplot of the square root transformed benthic organism density versus tide level represented by beach raking management. Data from survey sites across Follets Island and Galveston Island from 19 October 2012 to 20 May 2013 ($n = 8$). Simple linear regression fitted line (Adj. $R^2 = 0.239$, $P \leq 0.001$, df = 121).