Protecting Important Shorebird Habitat using Piping Plovers as an Indicator Species

Publication CBBEP – 96
September 1, 2014

<u>Prepared by</u>

David Newstead
Coastal Bend Bays & Estuaries Program
1305 N Shoreline Blvd., Suite 205
Corpus Christi, TC 78401

and

Kristen Vale
Environmental Institute of Houston
University of Houston-Clear Lake
2700 Bay Area Blvd.
Houston, TX 77058

Submitted to:
Coastal Bend Bays & Estuaries Program
1305 N. Shoreline Blvd., Suite 205
Corpus Christi, TX 78401

Final report to US Fish & Wildlife Service

In accordance with FWS Cooperative Agreement No. 1448-20181-A-J839

Protecting Important Shorebird Habitat using Piping Plovers as an Indicator Species

Prepared by: David Newstead

Coastal Bend Bays & Estuaries Program

1305 N. Shoreline Blvd, Ste 205

Corpus Christi TX 78401

and

Kristen Vale

Environmental Institute of Houston

University of Houston-Clear Lake

2700 Bay Area Blvd

Houston TX 77058

01 September 2014

BACKGROUND

The Piping Plover (*Charadrius melodus*) is comprised of three geographically distinct breeding populations, and is federally listed as Threatened throughout its wintering range. The species is generally present on nonbreeding grounds from late July through early May, meaning the nonbreeding period comprises approximately two-thirds of the annual life cycle. Since approximately half of the known population estimated from breeding grounds spends the nonbreeding season in Texas, it is critically important that the distribution of birds throughout this time is well understood in order to allow decision makers and managing entities to make informed decisions that may affect the species persistence and recovery. Piping Plovers are common on gulf beaches throughout most of Texas during the fall, and again in the spring; however, they can be absent from those beaches for long periods during the middle of the winter when they are presumably in bayside habitats. Identification of sites used by wintering Piping Plovers is of primary importance to their conservation.

The Texas Gulf coast is comprised of a series of primary and secondary bays separated from the Gulf of Mexico by long barrier islands perforated by seven passes, most of which are actively maintained by dredging. Coastal shorebird habitat associated with barrier islands includes the gulf beach as well as mud-, sand- and algal-flats that extend behind the islands towards the mainland. Tides on Gulf of Mexico beaches experience seasonal maxima in spring and fall, and seasonal minima in summer and winter, and these seasonal differences are greater than the diurnal tidal amplitude. Since bays are connected to the Gulf through narrow passes, the daily tidal amplitude in the bays is generally smaller than the astronomical tide acting on the Gulf beach, and consequently experience attenuated and lagged diurnal and fortnightly variations, but more profound seasonal fluctuations (Ward 1997). The bays typically experience the lowest annual water levels during the period from December through February, which are sometimes exacerbated by strong wind forcing from northerly cold fronts pushing water out of bays through passes. Shorebird microhabitat availability and suitability in the bays is accordingly dependent on the same seasonal tidal fluctuations, as well as wind influences (Withers 2002).

Barrier islands and bay shorelines are also under increasing pressure from human development. Modifications associated with development that may affect shorebird populations include filling and conversion of wetland habitats, increased activity including human and pet recreation, vehicle (conventional and ORV) usage, and beach “grooming” practices such as grading or raking/removing macroalgal wrack and debris. The two most heavily developed barrier island/bayshore systems in Texas are Galveston Island/Galveston Bay, and Mustang Island/Corpus Christi Bay. Piping Plovers have historically used both of these systems regularly during the nonbreeding phase though there is some evidence that populations may be declining in at least in the Corpus Christi Bay system (Foster et al 2009). Population trend in Galveston Bay is not known. Arvin (2010) showed that Hurricane Ike had a large impact on distribution of Piping Plovers on gulf beaches in the upper Texas coast, but it is not clear whether the total population declined.

While much can be learned based on surveys and observations of Piping Plovers (especially uniquely marked individuals), a more complete understanding of the way birds use habitat over a broader geographic area requires the ability to find specific birds when they are not readily located by conventional means. Radiotelemetry allows a researcher to follow and locate birds over a much larger area and can lead to the discovery of new areas previously unknown to support the species as well as patterns of habitat usage.

In addition to radiotelemetry, a series of beach surveys was conducted along a stretch of gulf beach in both study areas. The purpose of these surveys was to provide insight into the seasonality, abundance, and distribution of Piping Plovers and other shorebird species of conservation concern. These data are treated separately in Part II of this report.

During the course of the beach surveys and radiotelemetry project in Galveston Bay, a number of replicate benthic cores were taken from a range of beach sites with varying levels of human disturbance, shorebird usage, and beach management practices. Data from that effort is being analyzed by another investigator separately from this project so data is not included. However, beach survey data presented in this report will be integrated into the analysis of the benthic analysis project to provide a more robust analysis of variables that affect Piping Plover winter habitat usage.

The overall objective of this project was to generate information that would be informative for conservation efforts for Piping Plover generally as well as specifically in the Corpus Christi Bay and Galveston Bay systems.

STUDY AREAS

Corpus Christi Bay/Mustang Island

The Corpus Christi Bay (hereafter, "CCB") project area is comprised primarily of Corpus Christi Bay and Mustang Island, however since bird usage occurs around the perimeter of the bay, the adjacent bay/barrier island systems to the north (Redfish Bay/San Jose Island) and south (Upper Laguna Madre/North Padre Island) potentially influence total midwinter habitat usage of individual plovers (Fig. 1). The barrier islands vary widely in the amount of human development and associated pressure from beach recreation. San Jose Island is privately owned, and the beaches experience minimal visitation by passengers from a small ferry operating from Port Aransas, and this is mostly confined to the southmost portion adjacent to the North Jetty. The island is grazed by cattle, which sometimes visit the beach. Extensive mud and sand flats extend on the bay side of the island.

Figure 1. Corpus Christi Bay study area and important sites referenced. 1: Sunset Lake/Indian Point; 2: Pelican Island; 3: Charlie's Pasture; 4: Oso Bay; 5: Bulkhead Flats; 6: "Atlantis" bar; 7: Mollie Beattie Habitat Area

The Corpus Christi Ship Channel extends from the pass at Port Aransas to the Inner Harbor of Corpus Christi – a distance of approximately 36km. Dredge deposition from creation and maintenance of the channel has resulted in several large islands along the channel, some of which provide habitat for PIPL, especially Pelican Island. Mustang Island is intensively developed on the north end at Port Aransas, with constant and frequently high volumes of beach traffic (vehicles, people, dogs) and an active program of beach raking and sculpting to enhance recreational use. South of Port Aransas there is a series of non-adjacent properties developed as condominiums and residences interspersed with undeveloped coastal prairie and abandoned development sites. Mustang Island State Park encompasses 8.8 km of gulf beach as well as an extensive network of mud, sand and algal flats on the bayside shore. Recreational use is allowed throughout most of the park, though visitation of beaches is generally lower than on nearby beaches “cleaned” by city and county crews. Small islands in the southern part of the bay include dredge placement islands associated with the Gulf Intracoastal Waterway and other smaller dredged navigation channels, and a few natural islands. Extensive foraging habitat in the form of shallow sandbars is infrequently exposed during very low tides at which time they are known to be heavily used by shorebirds.

Packery Channel separates Mustang Island from North Padre Island. There is currently no beachfront development between the state park’s southern boundary and the northern jetty of Packery Channel. One planned development has been platted and streets and some infrastructure installed, but there has been no edifice construction since the development went bankrupt. However, beach traffic is usually very heavy on both the north and south (Padre Island) side of Packery Channel. During periods of high use, the beach is essentially a parking lot that extends to accommodate the volume at any given time. The dune system is broken at Newport Pass - a washover pass (which channels water across the barrier island during extreme high tide surges associated with tropical storms) approximately 1.5 km northeast of the channel. This is one of few beachfront sites where significant numbers of Piping Plovers can often be found roosting, particularly during high tides in the bay and/or inclement weather.

The northern tip of North Padre Island is comprised of beaches with high recreational usage, an elevated “seawall” with condominium developments, and extensive residential and canal developments on the Laguna Madre side. Though the shores of the channel are often heavily used by recreational fishermen, the seagrass, mud and algal flats fanning out to the north on the bay side of the pass are less frequently disturbed though they see some limited regular human use during waterfowl hunting season.

Oso Bay is a small embayment which drains the Oso Creek watershed and flows into Corpus Christi Bay on its south end. The shores of this shallow bay are comprised primarily of mudflats, though some shell bars are present near the confluence with Corpus Christi Bay. Piping Plovers are known to use the northern part of Oso Bay, which is bordered to the west by Ward Island (site of Texas A&M University – Corpus Christi campus (TAMUCC)) and to the east by Naval Air Station – Corpus Christi (NASCC).

Galveston Bay/Galveston Island

Galveston Island is located on the upper Texas coast, separating Galveston Bay and West Bay from the Gulf of Mexico (Figures 2-5). The island is separated from Bolivar Peninsula by an approximately 2.5km wide pass known as Bolivar Roads, which is the primary entrance of large ship traffic both to the Port of Galveston as well as the Port of Houston and associated refinery complex. There is no road crossing the pass but a regular ferry system is operated by the Texas Department of Transportation. The island is connected to the mainland by the Galveston Causeway. The west end of the island is separated from adjacent Follet’s Island by San Luis Pass – one of only two natural passes on the Texas coast relatively unaltered by major engineering projects. The entire island is within Galveston city limits with the exception of the City of Jamaica Beach which consists of a ~0.67km wide beach to bay swath in the middle of the island, consisting primarily of residential development. A seawall ~11.5km in length is located in front of the main part of the City of Galveston, with essentially no beach in front of the western half of seawall, and a series of small beaches formed by trapped sand between rock groins perpendicular to the seawall on the eastern half. East of the seawall is a ~5.6km stretch of beach which is managed as a park for recreation. A small area of beach and flats known as Big Reef extends along the inside of the ship channel west of the jetty.

Across Bolivar Roads from the east end of Galveston Island is Bolivar Peninsula. Bolivar Flats is an extensive saltmarsh and sandflat complex on the Gulf side of the peninsula adjacent to the jetty, which has formed through years of accretion as a result of the interruption of longshore transport of sand by the construction of the jetties. It is managed by Houston Audubon Society as a Shorebird Sanctuary. On the bay side of the peninsula, the Gulf Intracoastal Waterway is maintained between the peninsula and an extensive island formed by dredged material, with several associated areas of marsh/flats created for mitigation projects, mostly targeting creation of emergent aquatic vegetation (i.e. *Spartina* spp.).

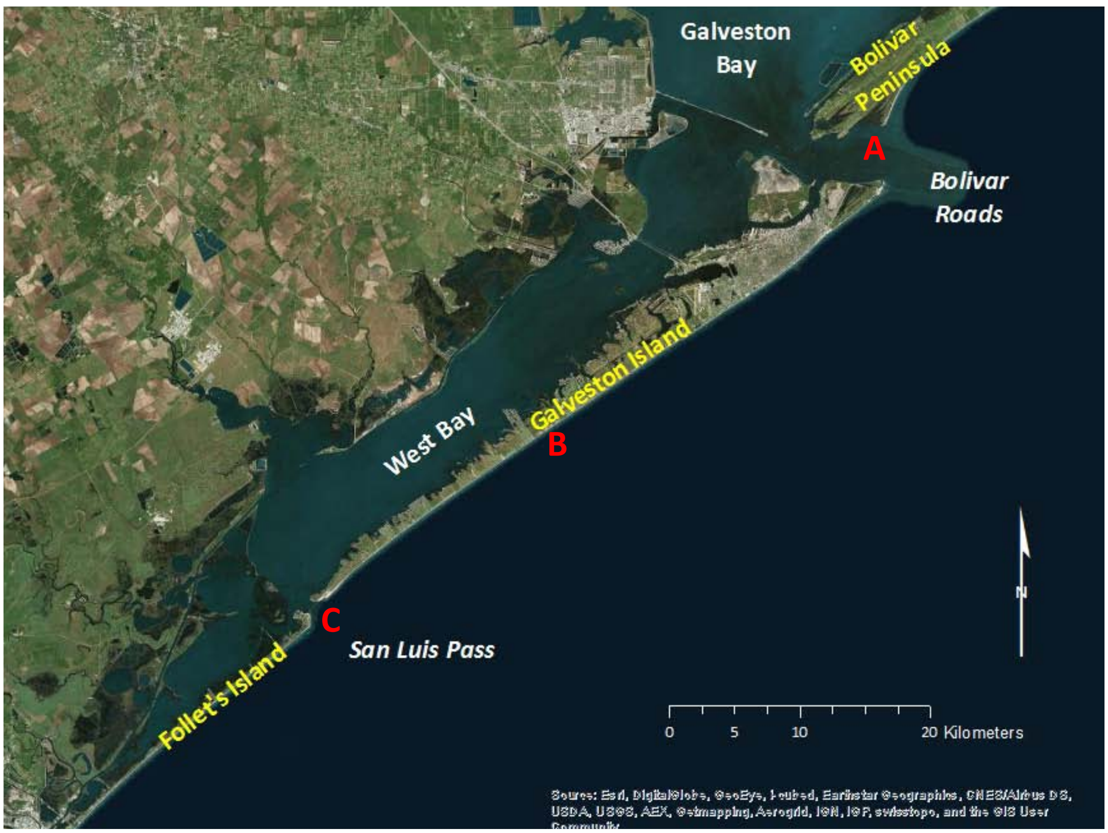

Figure 2. Galveston Bay study area and the three general areas where the radiotelemetry project was conducted – A) Bolivar Flats and Peninsula; B) Galveston Island State Park; and C) San Luis Pass (both sides of pass).

Figs. 3-5. Inset map showing habitats in each of the three areas of the Galveston Bay study area.

On Follet's Island west of San Luis Pass, a small residential development extends on the eastmost 1km of the Gulf beach and one small cluster of beachhouses on the western edge of the beach survey segment, and more extensive residential beachhouse communities west of the study area in the town of Surfside. Between Follet's Island and the mainland are Bastrop, Christmas and Drum Bays (from east to west), which are shallow bays featuring oyster reef, sparse seagrass, mudflat and emergent marsh as intertidal habitats.

As an active unaltered pass with considerable tidal exchange, San Luis Pass exhibits typical inlet features including an ebb tidal shoal, and a flood tidal shoal that is occasionally exposed during periods of very low water. West Bay Bird Island is a small part of one of these flood tidal shoals that is of sufficient elevation to support woody vegetation, and is used as a nest site by colonial nesting waterbirds.

CHAPTER 1. RADIOTELEMETRY

METHODS

Corpus Christi Bay/Mustang Island

A total of nine (9) Piping Plovers were captured and fitted with radio transmitters for this study (six captured with whoosh net, three with drop nets). Of these, two were captured on the gulf beach of Mustang Island, three were captured on Pelican Island adjacent to Corpus Christi Ship Channel, one was captured in Oso Bay, and the remaining three were captured on bay sites in the southern end of Corpus Christi Bay. All birds from this study were marked with a red flag (upper left), a blue band (lower left), and a unique combination of two other color bands (red, yellow, blue, green, black) on the right lower leg.

Galveston Bay/Galveston Island

A total of twenty-six (26) Piping Plovers were captured and fitted with radio transmitters for this study. All were captured on gulf beaches using a small cannon net in a seven day interval between 23-29 November 2012. Since a greater amount of tracking effort was available to be directed to the project in this study area, capture efforts were divided between three main areas, including the passes at each end of Galveston Island, and one site in the middle of the island. Nine (9) birds were trapped on the west end of Bolivar Peninsula, on the Gulf beach and nearby flats of Bolivar Flats Shorebird Sanctuary. Four (4) birds were trapped in the middle of the island on the Gulf beach side of Galveston Island State Park. Thirteen (13) were captured within 2km of San Luis Pass on either the west end of Galveston Island or east end of Follett's Island. All birds from this study were marked with a red flag (upper right), a white band (lower right), and a unique combination of two other color bands (red, yellow, white, blue, green, black) on the left lower leg.

Transmitter attachment

Birds were fitted with a 0.67g VHF coded transmitter with a 5 second burst interval (Lotek NTQB-3-2). All transmitters were on a single frequency (151.500 mHz), and a Lotek SRX-DL digitally encoded receiver was used for all relocation. Transmitters were attached to the skin of the intrascapular region using the following method: the person cradling the bird would part the feathers in the area by working them with both thumbs until a patch of bare skin was exposed. The other person would roll the transmitter in epoxy to coat all sides and lay the transmitter on the exposed patch of skin, and then pull the parted feathers back over the top and lay them flat against the transmitter and epoxy. The holder's thumbs were then used to apply steady gentle pressure on the feathers and transmitter to ensure a bond until sufficient drying time had elapsed. In 2011/12, Loctite 5-minute epoxy was used, while in 2012/13, Loctite 6-minute gel epoxy was used, since it had been shown to result in better retention based on another study (Newstead, unpubl. data). The bird was then released near the point of capture and observed to be sure that flight and other movements were not inhibited. No apparent injury resulted from either the capture or handling of birds in this study.

Relocation effort

Birds were tracked using radiotelemetry for the full active life of the transmitter using a combination of ground-, boat-, and aerial-based methods. For boat and ground-based methods, the birds were approached and visually located once detected by radio signal, so that other information could be collected on behavior and habitat. Locations were recorded by several methods. When birds were in an area that allowed an approach, a waypoint was taken with a handheld GPS unit at a point near the bird (in the same general habitat and usually within ~20m). On some occasions, once visual confirmation of the bird's location was made, a waypoint was taken and a corrected location was estimated using aerial imagery to ensure that the specific habitat type and general area being used was representative of the appropriate National Wetlands Inventory habitat classification. In some instances, when ground-based surveys were being conducted but a signal was detectable in a habitat across a deep body of water, a location was inferred based on direction and strength of signal and the availability of suitable habitat (i.e. an exposed shoal or intertidal oyster bed), and the location was assigned based on aerial imagery. This resulted in some points being "general" for a site, when the distance from the signal detected did not allow for a more specific location. However, based on visual observations from direct ground-based relocations, only one habitat type within an area was used when birds were present at those sites, so there is high confidence that locations that were not visually confirmed were likely associated with the same habitat (though behavior could not be inferred).

Aerial telemetry was conducted from a Cessna 172 equipped with a four-element Yagi antenna mounted on each strut at ~20^{o} angle to the ground, and a manually-operated switchbox in the cockpit to switch between antennae. At bay sites, multiple passes were usually made from different directions to best estimate the location of the radio signal and a waypoint taken as near as possible. Flights along gulf beaches were parallel to shore, so upon detection of a signal a waypoint was recorded at the point of strongest signal, and then "moved" to the gulf beach closest to the waypoint. Waypoint locations in the bay were adjusted in the data used for analysis based on field notes estimating direction and proximity of the signal and the most likely available habitat under those conditions.

Relocation efforts in the CCB study area primarily involved aerial and boat-based methods, with the exception of one bird (OB1) that was trapped near the Naval Air Station – Corpus Christi. Since this is restricted airspace, aerial relocation of this bird was only possible on rare occasions when the base was closed. Ground-based relocation was used extensively for this individual.

Relocation efforts in the GB study area were made primarily through ground- or boat-based methods. Aerial telemetry was conducted twice during this project, with emphasis on coverage of areas that were beyond the normal range of land/water-based approaches.

Additional birds detected: Simultaneously with this study, a separate radiotelemetry project (utilizing the same type of transmitter) was in progress in the Padre Island/Laguna Madre area of south Texas. Two birds from that project were detected by field crew in the Galveston component of this project. One bird (radio 114) from Padre study trapped on November 6, 2012 was tracked in the same general area through December 23, 2012, and was detected on one day at Corps Flats during this project. The code was repeatedly detected and de-coded by the receiver. It was not subsequently detected by either study. Another bird from the Padre study (radio 144) was trapped on February 1, 2013 on a flat in the Laguna Madre immediately south of Corpus Christi, then first detected on February 4, 2013 in the San Luis Pass area on the west end of Galveston. It was tracked through the remaining duration of this project.

RESULTS

Transmitter life

Transmitter life refers to the amount of time a bird was detected alive and carrying a radio that was transmitting a signal, and in this study averaged 52.4 d for the Corpus Christi study area and 92.5 d for the Galveston study area (Table 1). Resightings of radio-marked individuals (as determined by unique color band scheme) were included in this analysis if the bird was resighted prior to the latest date of a confirmed radio detection for that individual. In one case, a still-active transmitter was evidently shed and recovered near the site where the bird was present. No other shed radios were detected, so short transmitter life was either a function of battery failure or the radio being shed in an environment that would have effectively muted or destroyed the transmitter.

Days of exposure/mortalities

No mortalities of radiomarked individuals were detected in the CCB study area in a total of 419 transmitter-days. Two mortalities were detected in the GB study area in a total of 2276 transmitter-days. (See Appendix 4 for comments on mortalities).

Home Range Analysis

A minimum convex polygon (MCP, the smallest polygon containing all points in a series) was calculated for each individual bird in the study that was relocated four or more times. Mean MCP for eight birds with calculable home ranges was 392.2 ± 474.3 ha in the CCB study area, and 1406.9 ± 520.6 ha in the GB study area (Table 2). The shape of individual MCP home ranges are shown in Appendix 1 (these will be provided as GIS shapefiles with the final report or upon request).

Table 1. Mean number birds, relocations, active radio-tracked days, and Minimum Convex Polygon size for radioed Piping Plovers in the study. [a] does not include two birds that died during study

	n birds	*n* relocations [a]	*d* tracked [a]	MCP (ha) [a]
Corpus Christi Bay	**8**	**15.0 (11.6)**	**52.4 (25.1)**	**392.2 (474.3)**
Galveston Bay	**26**	**43.2 (11.7)**	**92.5 (3.4**	**1406.9 (520.6)**
Bolivar Peninsula	9	43.1 (12.0)	93.1 (3.5)	1162.0 (343.4
Galveston Island SP	4	47.0 (3.4)	92.3 (1.5)	819.9 (411.1)
San Luis Pass - Follet's side	6	46.2 (7.2)	91.0 (3.5)	2032.2 (232.4)
San Luis Pass – Galv. side	7	38.7 (17.0)	93.5 (4.4)	1540.5 (287.4)

All birds in the GB study were trapped on the Gulf beach, and subsequently were detected frequently in both beach and bayside habitats. Of the 9 birds trapped in the CCB study area, only two were trapped on the beach and were never subsequently detected anywhere but in bayside habitats. The seven birds that were trapped in Corpus Christi Bay were never detected on the Gulf beach. No bird in any of the sites in the GB study area was detected at another site, and though sites were not as discreetly selected in the CCB study area, no individual was detected outside the immediately adjacent bay or beach habitats from where they were captured, with the exception of one bird trapped in Oso Bay (CCB study area) which was detected one time in the flats on the south side of Corpus Christi Bay.

Habitat use patterns

In the CCB study area, the three birds trapped on Pelican Island showed extremely strong fidelity to that site through the duration of the project. Only one of the three was detected away from the island (on two occasions). Birds trapped in the southern end of Corpus Christi Bay were detected in various habitats throughout that area including algal flats, sandflats, and on exposed seagrass beds during times of extremely low water levels. One bird trapped in Oso Bay was detected outside of Oso Bay only one time, with the remainder spent between seasonally exposed mudflats and seagrass beds, and roosting on an exposed sand/shell bar near the entrance to Corpus Christi Bay.

In the GB study area, habitat usage patterns by birds from the three sites was very similar within sites. Birds trapped on Bolivar Peninsula were typically detected in either one of two locations – the Bolivar Flats Shorebird Sanctuary and adjacent gulf beach, or a newly-created marsh creation site known as the 288-Acre Marsh on the north side of the Gulf Intracoastal Waterway. Only two birds were detected across the ship channel at Big Reef.

Birds trapped on the beach at Galveston Island State Park were most frequently detected along the same stretch of beach, typically within a well-defined territory, but also made occasional use of bayside habitats including natural and created marsh sites.

Birds trapped on the beach near San Luis Pass made extensive use of tidally-exposed sandflats throughout the flood-tidal shoals within San Luis Pass. At times of seasonally-low water levels birds made more frequent use of mudflats within Bastrop and Christmas Bays, and occasionally were encountered roosting on an oyster shell rake separating the two bays. Though the Minimum Convex Polygons of all birds trapped in this area show considerable overlap at bay sites, detections on the beach were always on the same side of the pass on which they were initially trapped.

DISCUSSION

Results from radiotelemetry indicate that Piping Plovers in Corpus Christi Bay during midwinter are relatively sedentary compared with results of other studies. The mean MCP from this study (392.2 ha) is considerably lower than that reported for South Padre Island, TX (~1800 ha during winter, Drake et al 2001) or Oregon Inlet, NC (2010 ha, Cohen et al 2008). Since there were no mortalities in this study and no other indication of poor body condition, the small MCPs suggests that the system provides a sufficient mosaic of available habitats to support Piping Plovers within a relatively confined geographic space, at least during midwinter months. It must be noted that the mean MCP in the CCB area is largely an effect of the very low MCPs of the three birds trapped at Pelican Island, including two that were never detected anywhere else. While overall mean MCP of birds in the GB study area (1406.9 ha) was also less than that reported by Drake et al (2001) and Cohen et al (2008), the number of sites used by birds captured at each location was very small for the Bolivar and State Park birds, and since these sites were fairly close together the average MCP for the whole study is considerably lower than it would have been if the study had only included birds around San Luis Pass (mean 1805.3 ha). Consequently, one should use caution when interpreting MCP as a meaningful measure of home range on anything more than a localized scale.

While there was very strong overlap in habitat usage by the three birds from Pelican Island, there was somewhat less spatial overlap in home range of birds in the southern part of the bay. It is unclear whether less overlap is related to stronger territoriality or the fact that available habitat in the southern part of the bay is more widely distributed and simultaneously available. The loss or alteration of a specific site (such as a 3 ha algal flat) within the area would presumably result in a loss of fitness for birds that would otherwise use it only to the extent that other sufficient habitat is not readily available nearby, and to the extent that competitive interactions are not limiting the number of Piping Plovers the site can support. During this particular midwinter, we did not experience such anomalous tides or other conditions that would have resulted in the inavailability of virtually all habitats used by birds in this study; however, the midwinter period represents only a fraction of the nonbreeding phase of Piping Plover's annual cycle. At other times of the year, notably fall and spring, the seasonal water level is much higher, frequently inundating a large proportion of the habitats used this midwinter period. This coincides with the peak densities of Piping Plovers on gulf beaches, suggesting that for some birds the beach functions mainly as a refuge from inhospitable bayside habitats rather than an equivalently suitable alternate habitat. Factors affecting distributions and abundance of Piping Plovers on gulf beaches during times of high water in bays may therefore represent a more important constraint on the total number of birds the system can support.

Implications of sites used infrequently by large numbers of Piping Plovers

While all of the radioed birds stayed within a fairly limited area during the course of the study, some sites distant from the gulf beach occasionally hosted considerable numbers of Piping Plovers. Large numbers of birds were sometimes seen or reported in other locations for a short time. For instance, in the CCB area Sunset Lake and Indian Point provided limited habitat availability during most of the winter, but when flats were exposed briefly in the second week of January, between 12-20 Piping Plovers were found there. Similarly, in the GB study area there were occasions where one or sometimes all four of the birds marked at Galveston Island State Park were detected despite extensive searching. During at least one of these occasions, it was later reported that a large area of flats on the mainland shore near the Galveston Causeway had become exposed during extreme low midwinter tides. Small home range sizes determined in this study may therefore not be reflective of all birds in the system.

Pelican Island unique behaviors associated with ship traffic

With the exception of one bird that left Pelican Island twice – found both times in the moist algal flats of Charlie's Pasture – all other detections of birds trapped on Pelican Island were on Pelican Island, generally in the same flat where captured. The MCP for the two birds that were never detected away from the island for essentially two months are remarkably low, which suggests that essentially all critical components of the habitat mosaic necessary to support nonbreeding Piping Plovers are present on the site at least through the midwinter period. Observations of activity at the site revealed several factors that may at least partially account for this.

The passage of tankers along the Corpus Christi Ship Channel (on the opposite side of the island) creates a pattern of drawdowns and tidal surges (a pressure wake) on the flats. These events are detectable as sudden spikes/troughs in water level readings taken every six minutes by the Ingleside gauge (Texas Coastal Ocean Observation Network) in the ship channel. Plovers were often seen leaving areas they had previously been relatively sedentary and foraging aggressively as the water drew down suddenly. It is suspected that this drawdown occurs so quick relative to a normal tidal movement that many benthic organisms are unable to retreat quickly enough and so remain vulnerable to short-billed shorebirds such as plovers. Large drawdowns expose benthic habitat that might otherwise never be exposed by naturally-occurring low water events, and may consequently support a different benthic community. Several times Piping Plovers (as well as many Snowy Plovers, and two overwintering Wilson's Plovers) were seen to come off roost suddenly at the apparent sight of a tanker on the other side of the island, before an effect on water level was detectable by the observers. This indicates that this type of feeding strategy is a learned behavior rather than simply a response to immediately observable and actively changing conditions. The number of tanker passages during the day varies from zero to occasionally ten. One possible explanation for the very small home ranges of birds trapped on Pelican Island is that the episodic and sudden availability of high-quality prey items that might not be available under normal tidal conditions makes up for the otherwise small total area of the site. The island is also a colonial waterbird rookery, and as such is managed to be free of mammalian predators. This lack of predators probably further enhances the value of the site since plovers can roost undisturbed on the high flat immediately adjacent to feeding areas.

Usage of sites created or modified by dredge material

Despite considerable areal extent of DMPAs in south Texas, Zonick et al (1998) recorded only 2% of the total telemetry relocations in this habitat type. Other DMPAs along the Corpus Christi Ship Channel are used only infrequently by individuals or small numbers of Piping Plovers, but the three Pelican Island birds in this study were never detected there. The site tenacity exhibited by Piping Plovers on Pelican Island and the high numbers that can occur there at times is likely attributable to the presence of several high quality habitats in a small area, with that habitat value possibly enhanced by the effects of tanker passage, as well as proximity to other alternative habitat options such as Charlie's Pasture on the back of Mustang Island. DMPA placement may have a positive net effect on Piping Plovers in this particular case, however dredge placement in other systems is suspected of inducing tidal alterations that have decreased habitat availability and/or suitability (Zonick et al 1998). The unique confluence of factors at Pelican Island merits further investigation as a case study, as its evolution as an important site for Piping Plovers and other shorebirds is due to the specific dynamic hydrological, geological, and ecological processes unique to the site. Understanding these processes and incorporating them into sediment management plans may result in improved value of future projects intended for beneficial use. Since only tankers produce significant pressure wakes of the type discussed here, the potential for habitat enhancement of this type may be limited to areas in proximity to major ports.

In the GB study area, several "created" sites were used by birds in this study. Due to loss of important subtidal and intertidal habitats due to erosion, subsidence and sea level rise, a series of habitat creation projects on the bay side of Galveston Island and the Bolivar Peninsula have been constructed in the past two decades, some as mitigation and others via other funding sources. The projects are generally engineered for creation of habitat types such as seagrasses and saltmarsh (*Spartina* spp.), and typical designs include marsh mounds (in which dredged material is pumped until it becomes emergent and the pipe is then moved nearby and repeated) or marsh terracing (involving more extensive use of heavy machinery to sculpt the material into terraces). After initial construction, some of these are planted with borrowed plant materials while some rely on natural recruitment. Piping Plovers in this project used at least three of these created marsh sites. Two created marsh sites on the bay side near Galveston Island State Park were used. These two projects were completed at different times. Of the two, Piping Plovers were more frequently detected at the most-recently created site, which features slightly higher elevations and more exposed flats, whereas vegetation at the other site has reduced the amount of exposed flats available to shorebirds. The most heavily used site was the most recently constructed site known as 288-Acre Marsh on Bolivar Peninsula. This project was completed in early 2012 and was thus less than a year old when the Galveston Bay component of this study began. This site features an extensive area of newly-created marsh terraces protected from the north by a rock breakwater. The project was constructed as a project to mitigate for loss of emergent aquatic vegetation (*Spartina* spp), and planting was to commence in the winter/spring during this study. It was not previously known that Piping Plovers would use this site so extensively. Once it became clear just how important this site had become, plans for planting this season were modified to limit the impact to foraging birds while ensuring the mitigation project could achieve its success criteria.

While marsh creation projects generally have substantial benefits for a variety of bird guilds, the birds that are most likely to benefit from the habitat the projects are intended to create are marsh birds, wading birds, and those that derive ancillary benefit from more productive fisheries. The sites are also sometimes designed in a way that they protect an important shorebird site from further erosion. However, in the early succession of marsh creation projects, these sites have the potential to provide a considerable amount of habitat for shorebirds such as Piping Plovers in areas where that habitat never existed or has not existed for a long time. The presence of an additional feeding site proximate to other areas typically used by Piping Plovers could provide at least a short-term benefit to the population. Piping Plover habitat at Bolivar Flats Shorebird Sanctuary was heavily damaged during the passage of Hurricane Ike in September 2008, and counts of Piping Plover at the site decreased following that event (Arvin 2009). The number of Piping Plovers seen at the site has increased slowly but steadily over years as habitat has improved at Bolivar Flats, and it is now supporting numbers closer to other counts from multiple years prior to Hurricane Ike (S. Maddock, pers. comm.). Considering that many of the radiomarked birds at Bolivar moved together between these two sites, it is possible that this marsh creation could at least temporarily provide habitat for an increased number of plovers.

Bird mass between areas and years

Birds trapped in 2011 in the Corpus Christi Bay (CCB) study area were significantly lighter than birds from Galveston in 2012, though they did not differ in any of the other three morphometric measures (head length, exposed culmen, flattened wing chord). Since the project was done in successive years in the different areas, it is not possible from just those data to ascertain whether the difference was attributable to region or to the year. In order to better assess this difference, additional data from another project was incorporated into analysis. This data included the same measurements on birds captured in the Upper Laguna Madre (ULM) area (adjacent to CCB) in both 2011 (n=5) and 2012 (n=36). Again, all morphometrics, excluding weight, were similar among groups and years for birds captured in the ULM, CCB, and GB areas. Since ULM and CCB are adjacent and capture locations were essentially contiguous, data from these two study areas in 2011 were pooled, allowing a comparison between south Texas coast (ULM, CCB) in 2011 with south Texas coast (ULM only) and the upper coast (GB) in 2012. Mass in south Texas (48.0 ± 3.1g) was significantly ($F=18.45$, $p<0.0001$) lower in 2011 than in both south Texas (53.6 ± 3.6g) and Galveston (55.8 ± 4.6g) in 2012.

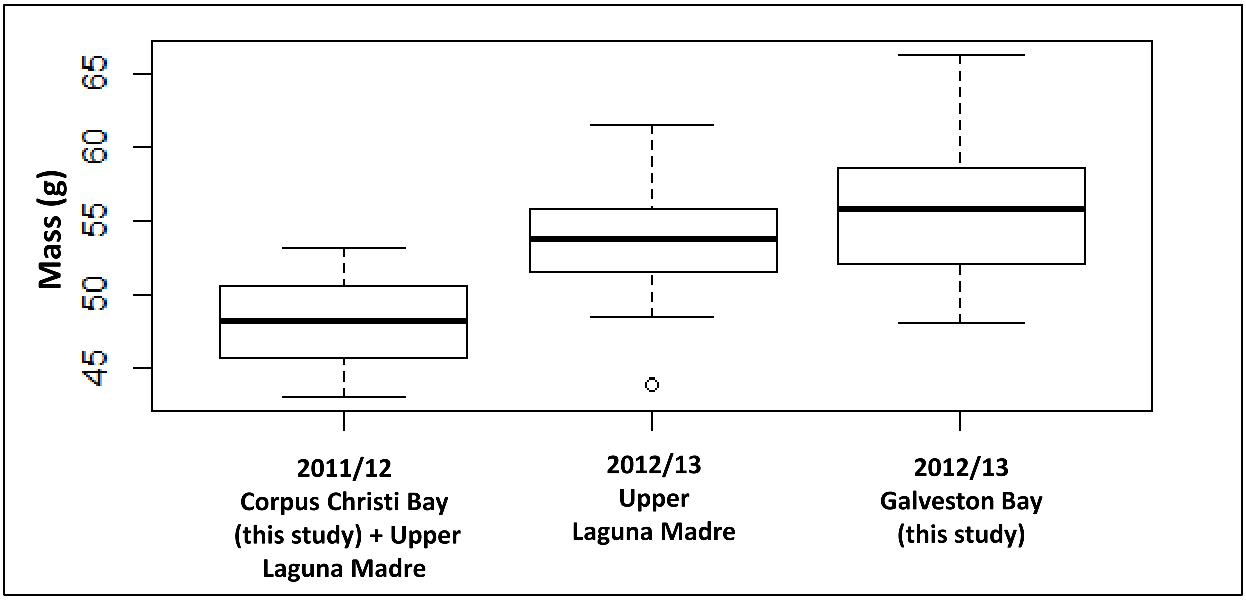

Figure 6. Mass of captured Piping Plovers in this study and a concurrent study in 2012/13. Corpus Christi Bay and the Laguna Madre study area are adjacent and located on the lower Texas coast. Galveston Bay is on the upper Texas coast.

It is possible that this difference represents true interannual variation in weights, but these findings should also be considered in light of the major red tide outbreak that occurred in the winter of 2011, which was centered on the south Texas coast. During work on the Padre Island project, several Red Knots were captured by hand or found dead, and some carcasses were tested. Extremely high levels of brevetoxin were detected in liver, gastrointestinal tract, and muscle samples and the mortalities were attributed to that exposure (Paul Zimba, Center for Coastal Studies, Texas A&M University-Corpus Christi, pers. comm.). While no Piping Plovers were confirmed to have succumbed from brevetoxin exposure, one bird (captured by hand by a park visitor and taken to a rehabilitation facility) was suspected to have been weakened by the exposure, and the known mortality of a bird in this study may also have been similarly weakened.

CHAPTER 2. GULF BEACH SURVEYS

An additional series of Gulf beach surveys was conducted as a complement to this project, in order to assess seasonality, abundance, and distribution of Piping Plovers (and several other species).

Corpus Christi study area

A 43km stretch of gulf beach from Access Road 2 on Mustang Island south to the 5 mile marker on Padre Island National Seashore was surveyed approximately weekly from July 27, 2011 through May 9, 2012 (Fig. 6). This included 11 km of Mustang Island beach and 32 km of North Padre Island. The survey area was divided into seven distinct segments based on access points and management/ownership. Surveys were always conducted from north to south within a segment, but the order in which segments were surveyed was randomized to the extent practical to minimize the potential influence of time of day on survey results. Vehicles, humans, dogs (leashed and unleashed) were tallied between bird observations to demonstrate patterns of anthropogenic factors within survey segments.

Galveston study area

A 35 km stretch of Gulf beach from the east side of Galveston Island State Park to the eastern border of Surfside Village was surveyed weekly between August 3, 2012 and May 25, 2013 (Fig. 7). Surveys were conducted along 14.7 linear beach kilometers of Follet's Island and 21 linear beach kilometers on Galveston Island. Additionally, San Luis County Park on the Follets Island side of San Luis Pass was surveyed in its entirety during the surveys (segment 9). The site includes beach along the shoreline of the pass as well as an internal lagoon. A total of 43 beach surveys were conducted with the survey day alternating between a weekday and a weekend day throughout the study duration. Survey segments were similarly dictated by access points, and the entire survey route was also subdivided into one kilometer transects (to allow for comparison of human use parameters on a per km basis as well as per segment).

Surveys were classified into season based on Noel and Chandler (2008): fall – August through October; winter – November through February; spring – March through May. The first survey of the Corpus Christi study area (July 27, 2011) was also included in the fall category since the species does not breed or oversummer (in significant numbers) in the area. Surveys were complete with the following exceptions in the Corpus Christi study area: July 27, 2011 – Segment 6 was not surveyed because of lack of access; August 10, 2011 and August 17, 2011 – Segment 3 not surveyed. These were included in the analysis, though other surveys were excluded if multiple segments were not surveyed (for instance, for vehicular problems), or for GPS malfunction.

Information on management, ownership, and patterns of usage is provided in Appendix 3.

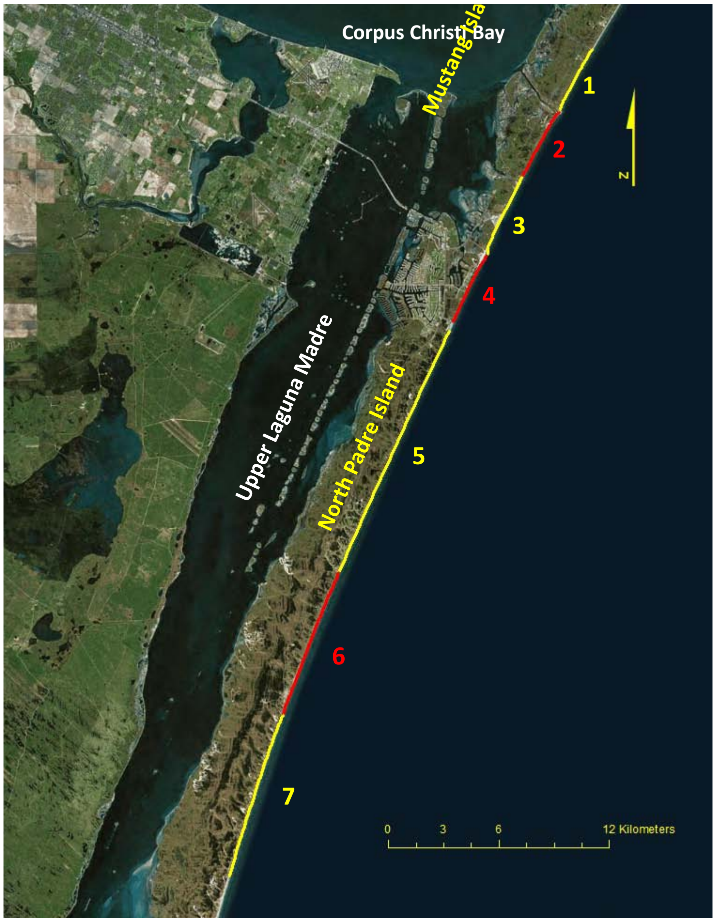

Figure 7. Beach survey segments on North Padre and Mustang Islands.

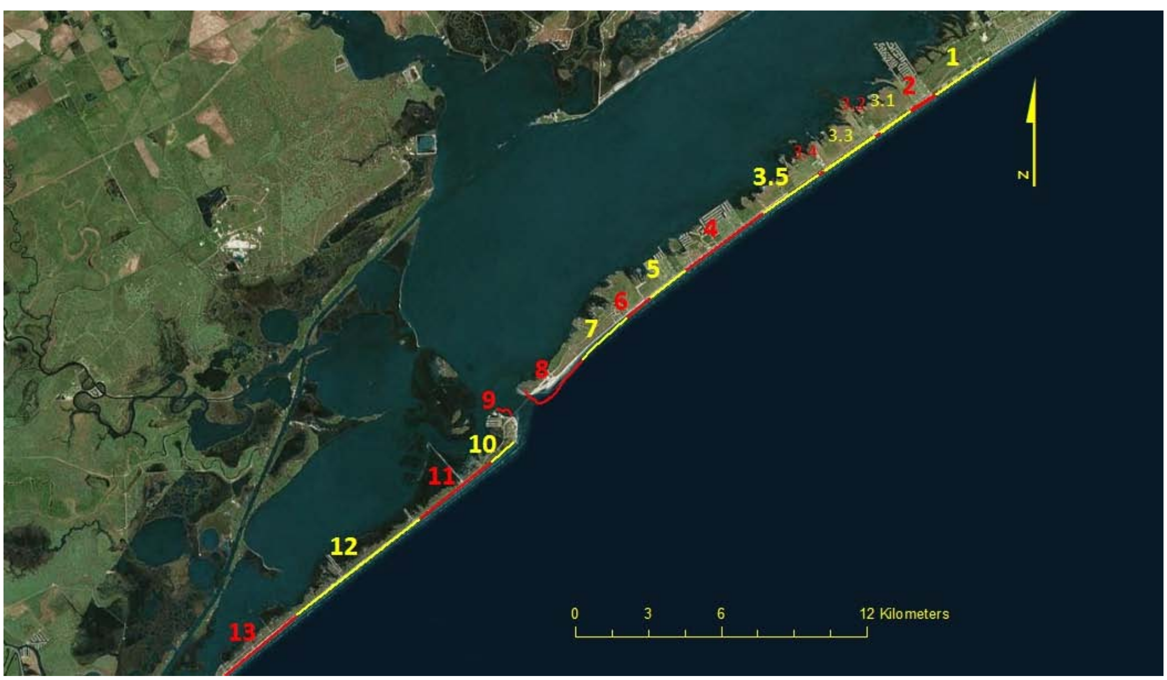

Figure 8. Beach survey segments on Follet's and Galveston Islands.

Observers recorded the location of each Piping and Snowy Plover (also Wilson's Plover, Red Knot, American Oystercatcher) and carefully observed each bird to detect the presence of bands. Band combinations were recorded for all marked birds.

Data was tabulated by kilometer for each of the focal bird species in both study areas, and also for the four anthropogenic factors (people, vehicles, dogs leashed, dogs unleashed) in the Galveston study area. A shapefile in ArcMap was created incorporating each occurrence of a bird (or group of birds). The survey route is linear in nature though the presence of a recorded waypoint could vary from that line depending on where the vehicle was at the time the point was recorded. The recorded points were "corrected" to the survey route line by using the Near function (Spatial Analysis Tools). To facilitate visual interpretation, the points were then moved an equal distance in an offshore direction, and a point density raster was created to illustrate density on a color ramp using 12 classes, with the lowest class level left uncolored. Classes were equally sized for the full survey dataset based on the actual density values. For analysis of seasonal distribution, the class sizes were manually adjusted to correct for uneven numbers of surveys between seasons, and to provide an illustrated context of the differences in relative use of gulf beaches between seasons (i.e. since 13 of the 35 surveys were in the fall, class size was 37.1% (13/35) of the class size in the full dataset).

Behaviors were categorized as either feeding or roosting (including preening) in the Galveston study area beach surveys, but was not recorded for every observation in the protocol for the Corpus Christi study area surveys. Therefore, data are presented differently.

During beach surveys in the Corpus Christi study area, aggregations of birds greater than 3 individuals were typically roosting when first observed so observations of Piping and Snowy Plovers in groups of 4 or more were mapped and then categorized into general areas.

RESULTS

A total of 4,672 observations of Piping Plovers and 1,902 observations of Snowy Plovers were recorded during the surveys. These data are summarized in Table 2. Piping Plover density (individuals per km) was 1.83 in Galveston study area and 1.27 in Corpus Christi study area. Snowy Plover density (individuals per km) was 0.79 in Galveston study area and 0.48 in Corpus Christi study area. The highest seasonal density of Piping Plovers was recorded in fall 2011 in the Corpus Christi study area (2.65 individuals/km) but density was much lower in both winter and spring (0.42 and 0.54 individuals/km respectively). Snowy Plover density in the Corpus Christi study area was similarly higher in winter and decreasing through winter. By spring they were only occasionally recorded. In the Galveston study area total Piping Plover density was relatively consistent through all seasons. Snowy Plover density was similar between fall and winter but declined in spring.

Figures 8 through 11 illustrate the mean densities of Piping and Snowy Plovers, and humans and vehicles for the beach surveys. It must be noted that comparisons between the Galveston study area and the Corpus Christi study area should not be considered direct. Because surveys in the Galveston area were conducted alternately on a weekend day and a weekday, the levels of human and vehicle presence are likely much higher when taken on average. Also, since these variables were recorded on a per-segment basis rather than per-kilometer basis in the Corpus Christi area, there is less resolution available to make inferences about relationships between human factors and bird presence. For instance, human activity was not uniformly distributed throughout most segments resulting in a lower mean density for the segment than would have been recorded within some kilometers in that segment.

Table 2. Mean number of Piping and Snowy Plovers per kilometer (and total observations) for each study area by season.

		Piping Plover			***Snowy Plover***		
		Mustang	**North Padre**	**TOTAL**	**Mustang**	**North Padre**	**TOTAL**
2011-12	Fall (n=13)	2.77 (396)	2.61 (1085)	*2.65 (1481)*	0.64 (91)	1.09 (452)	*0.97 (543)*
	Winter (n=15)	0.27 (44)	0.47 (227)	*0.42 (271)*	0.23 (38)	0.27 (129)	*0.26 (167)*
	Spring (n=7)	1.22 (94)	0.31 (69)	*0.54 (163)*	0.01 (1)	0.04 (9)	*0.03 (10)*
	Total (n=35)	**1.39 (534)**	**1.23 (1381)**	***1.27 (1915)***	**0.34 (130)**	**0.53 (590)**	***0.48 (720)***
		Follet's	**Galveston**	**TOTAL**	**Follet's**	**Galveston**	**Total**
2012-13	Fall (n=13)	1.93 (351)	2.03 (554)	*1.99 (905)*	1.65 (301)	0.50 (136)	*0.96 (437)*
	Winter (n=18)	1.28 (322)	2.19 (827)	*1.82 (1149)*	1.44 (363)	0.62 (235)	*0.95 (598)*
	Spring (n=12)	0.94 (158)	2.16 (545)	*1.67 (703)*	0.46 (78)	0.27 (69)	*0.35 (147)*
	Total (n=43)	**1.38 (831)**	**2.13 (1926)**	***1.83 (2757)***	**1.23 (742)**	**0.49 (440)**	***0.79 (1182)***

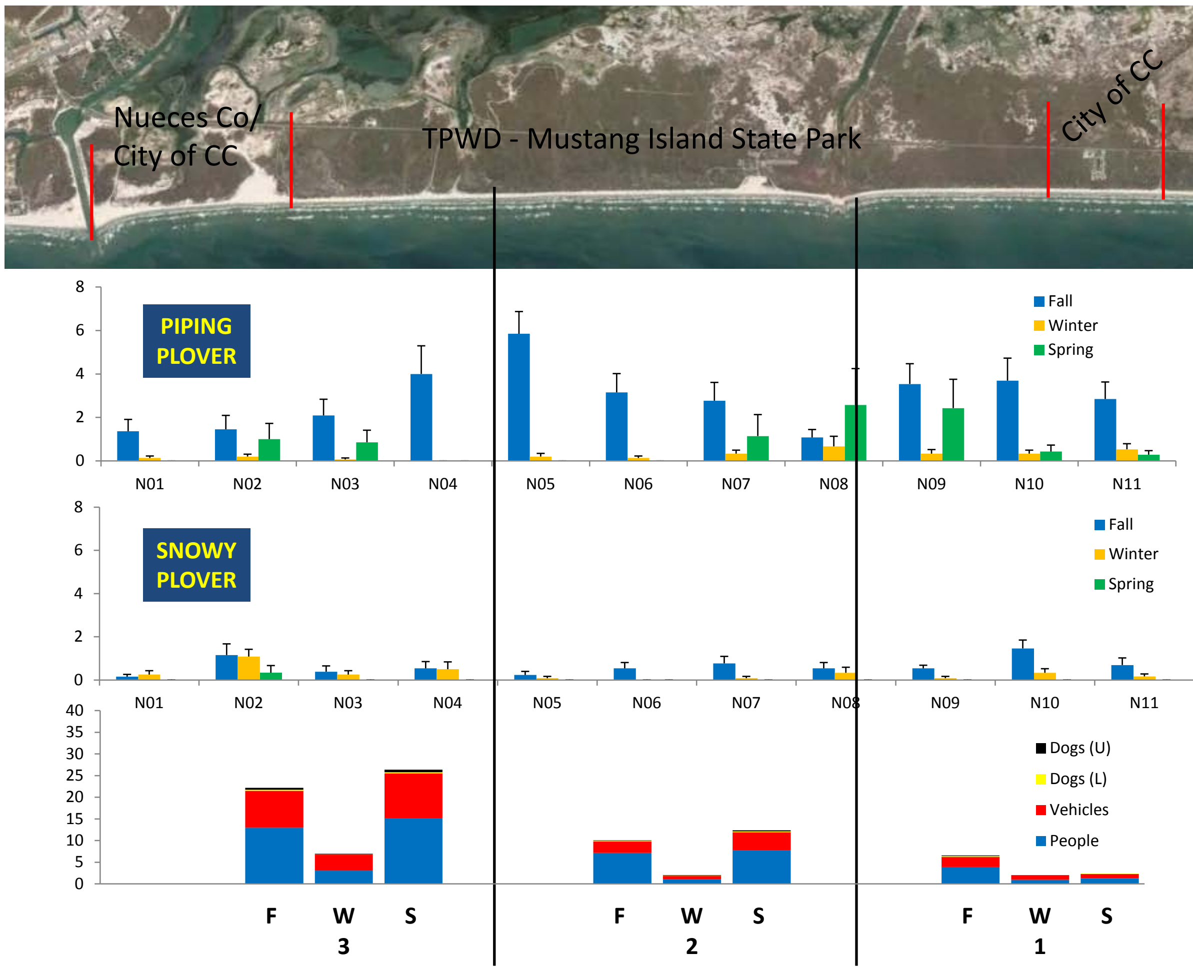

Figure 9. Mean number of individuals of Piping and Snowy Plovers per kilometer observed on beach surveys on Mustang Island during 2011/12 nonbreeding season. Anthropogenic factors were grouped based on survey segment rather than kilometer. Black lines through graphs delineate segments; red lines on image delineate management entity.

Piping Plover distribution on Mustang Island was mainly concentrated within the boundaries of Mustang Island State Park, but Snowy Plover densities were fairly low throughout. Density of both species associated with kilometer N02 was primarily associated with roosting birds using the expansive sand flats extending westward from the beach at Newport Pass. Human usage of the beach was substantially higher within Segment 3. Human use data was not collected on a per kilometer scale in this study area, but the distribution of human presence was highly skewed towards the southern end of this segment (especially N01 and to a lesser degree N02).

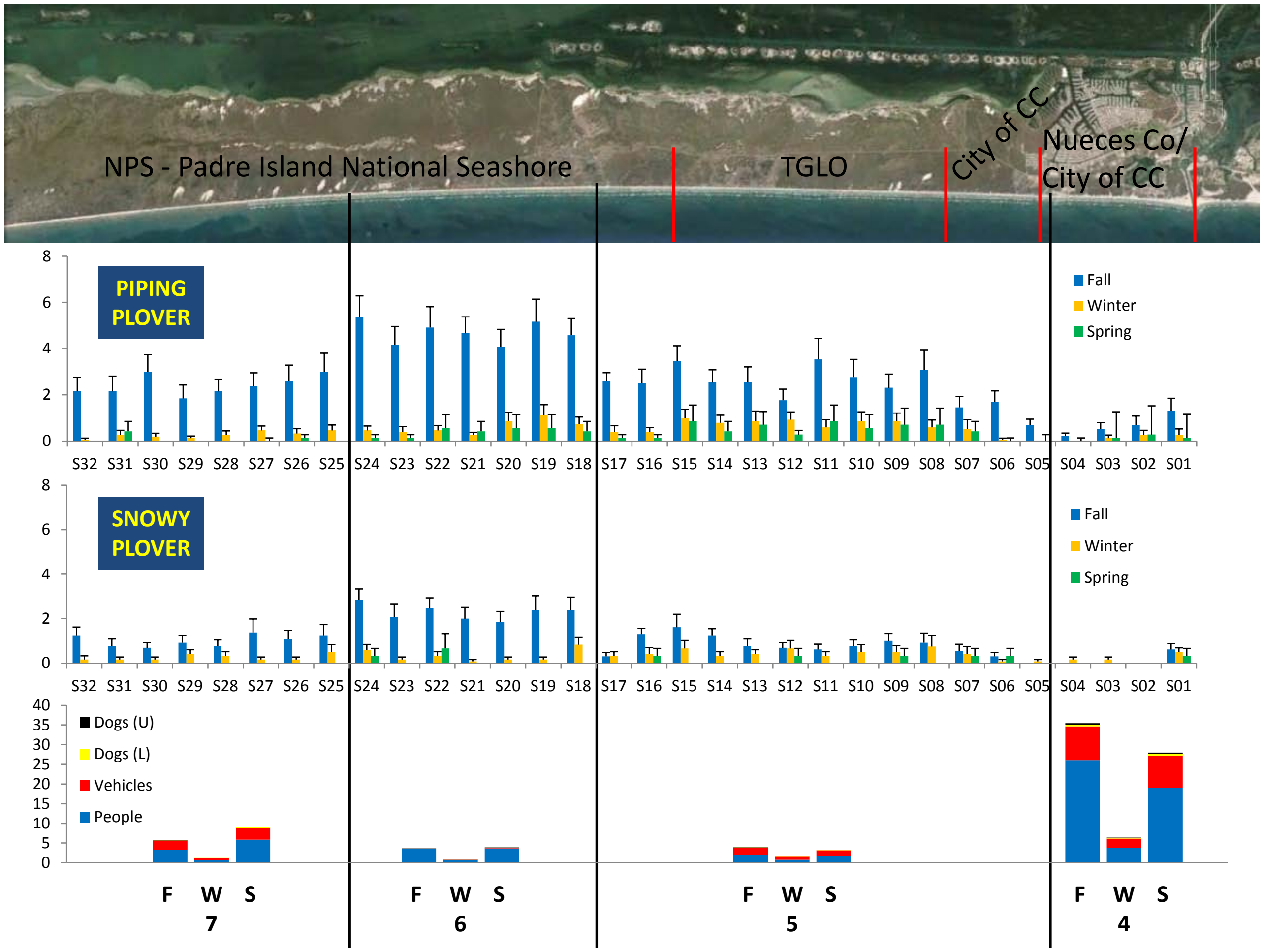

Figure 10. Mean number of individuals of Piping and Snowy Plovers per kilometer observed on beach surveys on North Padre Island during 2011/12 nonbreeding season. Anthropogenic factors were grouped based on survey segment rather than kilometer. Black lines through graphs delineate segments; red lines on image delineate management entity.

Overall both Piping and Snowy Plover distributions on North Padre Island were lowest in Segment 4 (between Packery Channel south jetty and Bob Hall Pier) and highest in Segment 6 (Malaquite Beach – Padre Island National Seashore). For both species, densities in Segment 6 were considerably higher than all other segments during fall. Though density dropped in all segments in winter, densities of both species were higher in Segment 5 in this season.

Human use was higher in Segment 4 than other segments on North Padre Island. Similar to Segment 3 on Mustang Island, there were frequently high concentrations of people adjacent to the jetty, but people were distributed more evenly throughout the segment during high use periods. Lowest overall use was recorded in Segment 5. Though more people were recorded in Segment 6, there were only very occasional observations of vehicles since this is a pedestrian beach (vehicles seen were associated with National Park Service staff, sea turtle patrols, or other researchers). Within this segment, people were primarily concentrated in front of the Malaquite Beach Pavilion Visitor's Center in kilometers S23 and S24.

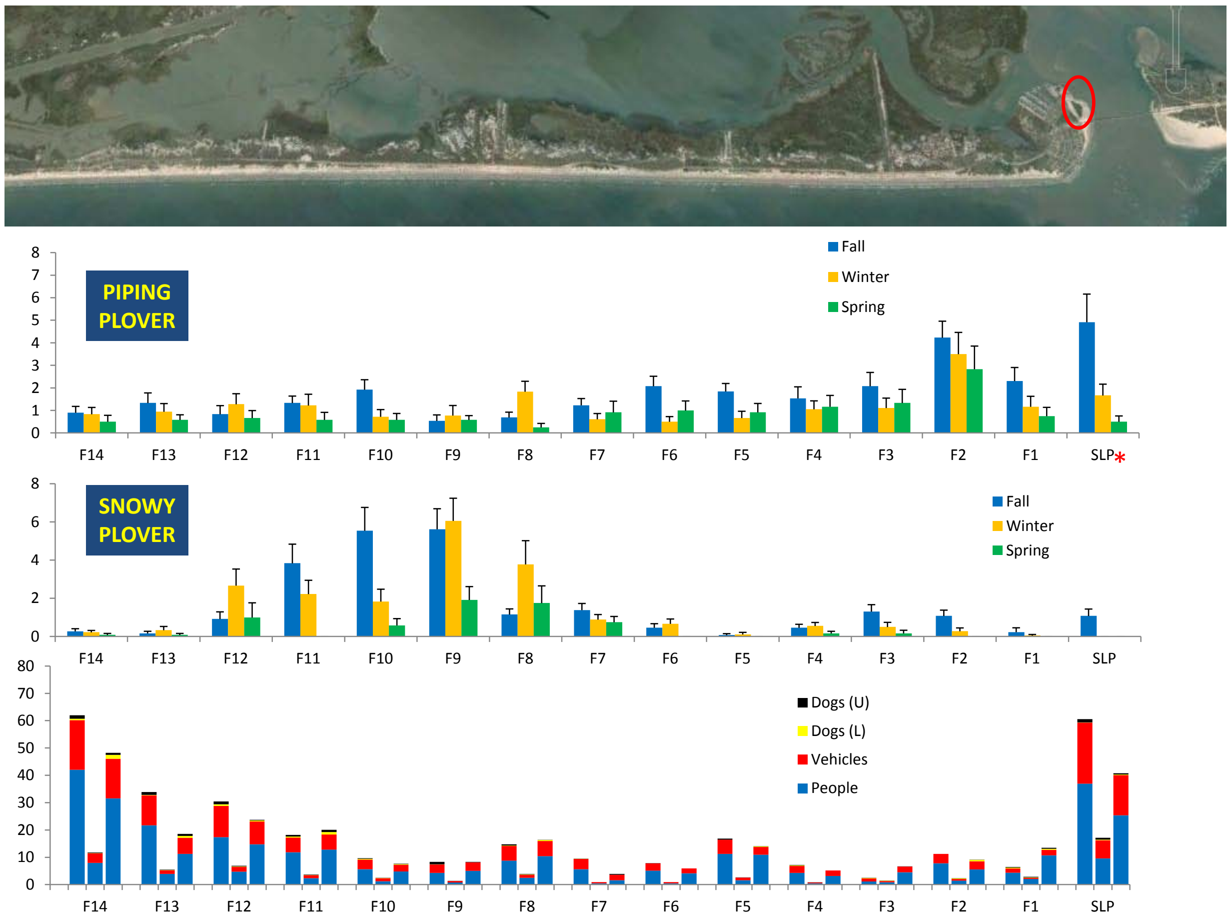

Figure 11. Mean number of individuals of Piping and Snowy Plovers, and anthropogenic factors per kilometer (except SLP) observed on beach surveys on Follet's Island during 2012/13 nonbreeding season. San Luis Park (SLP) is not a linear segment so was surveyed in its entirety (shoreline as well as interior lagoon), so data is not on a per kilometer basis.

While overall Piping Plover density was somewhat lower on Follet's Island than on Galveston Island, some of the highest densities of Snowy Plovers were recorded there, concentrated mainly in kilometers F8 through F12. With the exception of a small low-rise condominium complex and three non-adjacent homes in kilometers F3 and F4, there are no permanent structures seaward of the highway in the first 12 km of Follet's Island and only two small sparsely populated developments on the bayward side.

Human use on Follet's Island was concentrated mainly on the western quarter of the survey route near the village of Surfside, and also at San Luis Park.

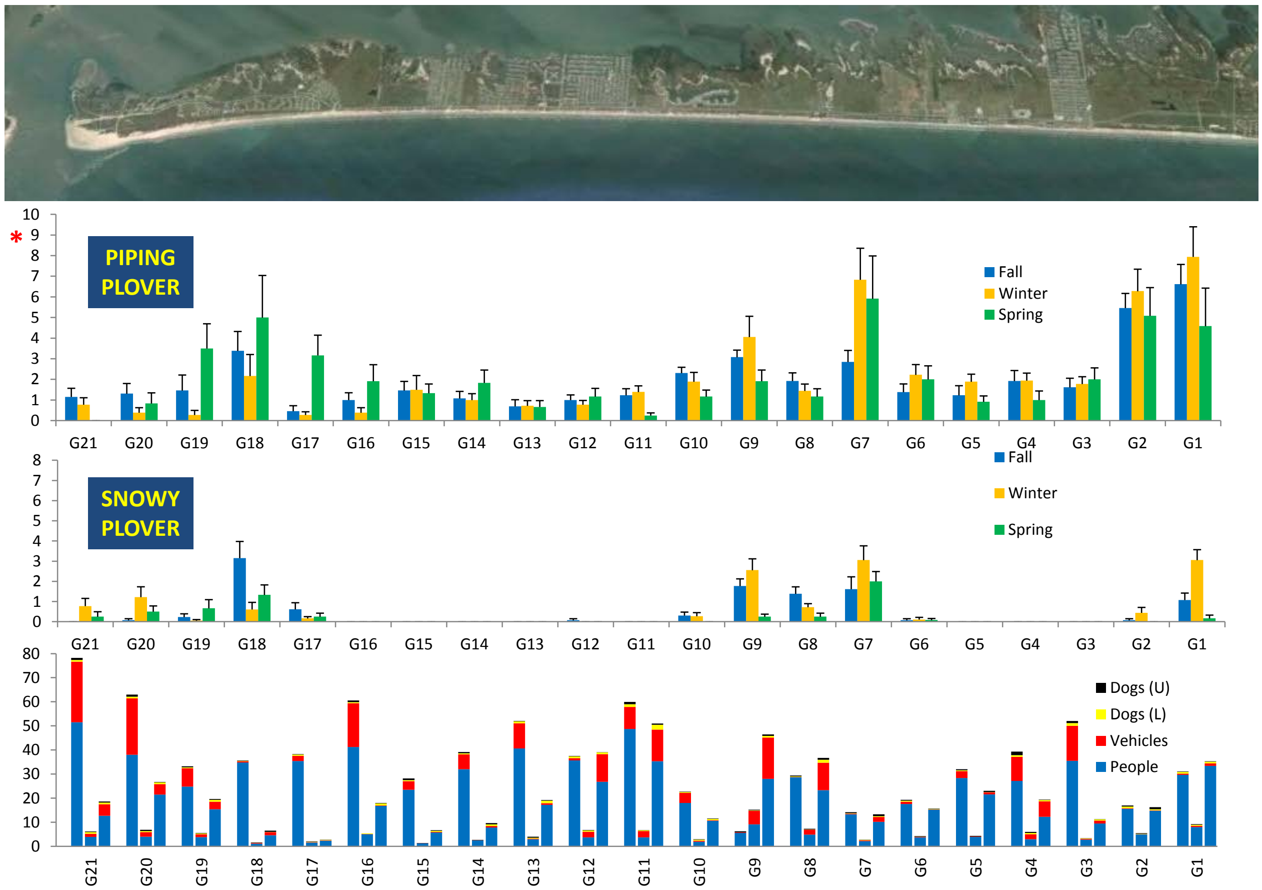

Figure12. Mean number of individuals of Piping and Snowy Plovers, and anthropogenic factors per kilometer observed on beach surveys on Galveston Island during 2012/13 nonbreeding season.

Though Piping Plover usage was consistent throughout most of the Galveston Island survey route, several areas showed substantially higher densities. While Snowy Plovers were far less numerous on Galveston Island than on Follet's Island, the areas where they were found in higher densities generally correspond to areas that also had higher than average Piping Plover density. Kilometers G1 and G2 are entirely within the boundaries of Galveston Island State Park. Kilometers G7 through G9 are areas with only one line of homes seaward of the highway and with little to no development on the bay side of the highway. Kilometers G17 through G19 are located in front of the Pointe West residential community. The beach there is considerably wider than anywhere eastward of this point, and while there was a substantial amount of human presence on this stretch in fall, there was very little vehicular traffic. Both human and vehicle presence was much lower there in both winter and spring.

Roosting

Roost sites are typically very well-defined in the Corpus Christi study area (i.e. roosts tend to be fairly spatially-fixed in association with certain geographic features rather than occurring somewhat randomly along the beach). Figs 13 and 14 illustrate the areas where roosting concentrations were encountered.

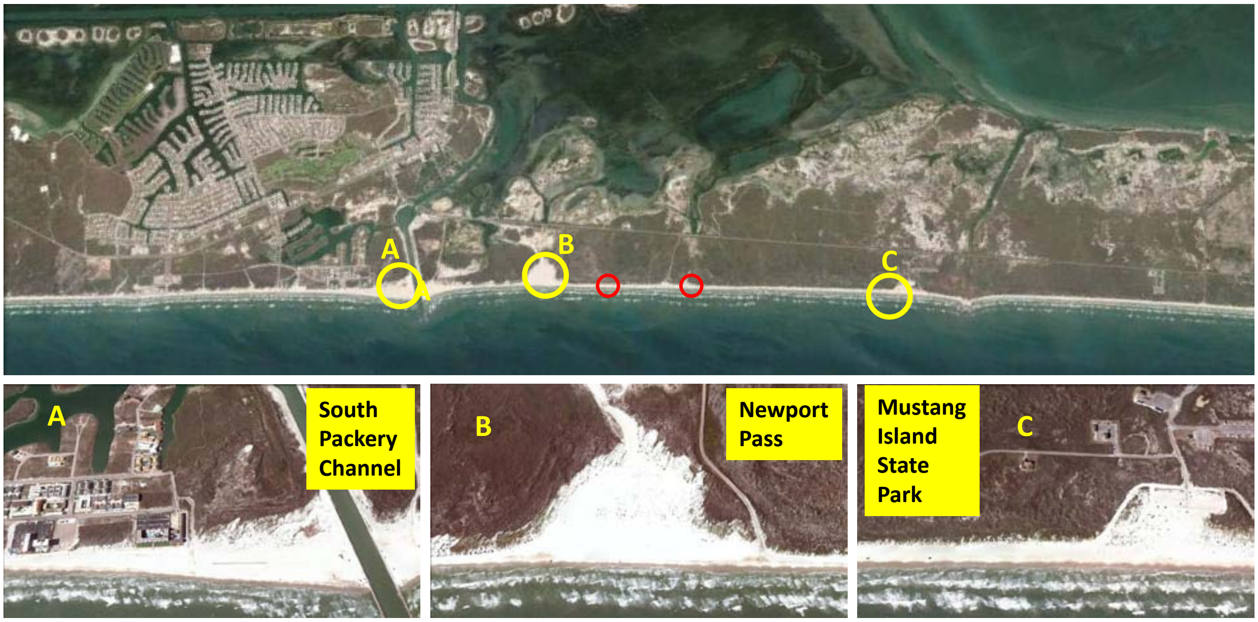

Figure 13. Sites in northern half of CCB beach survey areas where roosting concentrations (>4 ind.) of Piping and/or Snowy Plovers were encountered. Yellow circles and insets refer to commonly used sites; red circles denote infrequently used roosts.

Both the South Packery Channel and Newport Pass sites are characterized by a sandy beach area that extends much farther landward than is typical along the rest of the beach. Since the opening of Packery Channel and placement of jetties, sand has accumulated and built the beach on the south side. Low coppice dunes of loose sand are situated landward of the usual beach-driving activity. Newport Pass is a historical washover pass that becomes connected to the Laguna Madre across the island during storm surge events usually associated with tropical storms. A line of bollards extends across the pass parallel to the beach but behind the main dune line to prevent traffic crossing all the way to the highway. Both Snowy and Piping Plovers were encountered roosting in the loose sand and debris landward of the majority of beach traffic but seaward of the bollards. While there is a superficial resemblance to the pedestrian beach at Mustang Island State Park and the other two sites in Fig 12, the locations of roosting birds were not within this area but rather immediately south of the bollards. The South Packery Channel site is on the North Padre Island side of Packery Channel, but observations of marked birds indicate this site is primarily used by birds that are commonly encountered in the sand and algal flats on the Corpus Christi Bay side of Mustang Island.

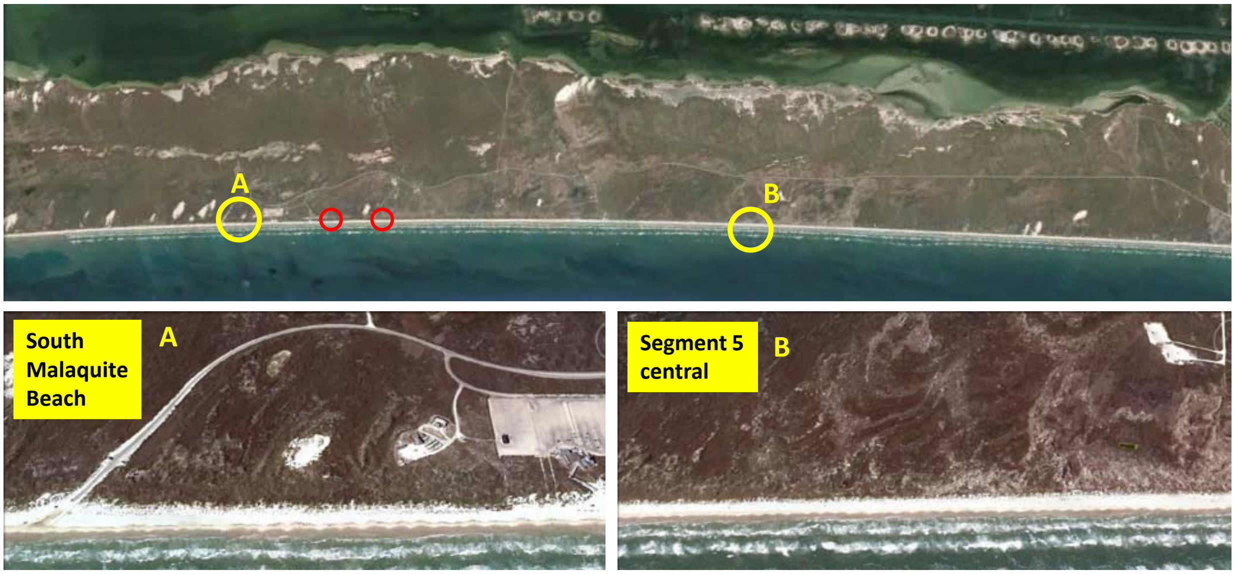

Figure 14. Sites in southern half of CCB beach survey areas where roosting concentrations (>4 ind.) of Piping and/or Snowy Plovers were encountered. Yellow circles and insets refer to commonly used sites; red circles denote infrequently used roosts.

There were several areas where roosting birds were encountered along the 8.3 km Malaquite Beach section of Padre Island National Seashore, but the most frequent observations of roosting birds were between the beach in front of the Malaquite Beach Visitors Center, and the bollards delineating the south end of pedestrian-only Malaquite Beach from “South Beach” where driving is permitted and this is the only beach access from this point south. In Segment 5, there were occasional encounters of roosting birds throughout its length, concentrated mainly in the central section. There was not a specific point of roost occurrence and no geographical features appeared to distinguish the area from other parts of the beach, but it is approximately 9 km south of the beach access at the north end of Segment 5, and 3 km from the beach access at the south end.

In the Galveston area beach surveys, roosting behavior was also observed throughout the survey area though there were notable differences between species and seasons (Figures 14-19) . There were relatively few records of roosting aggregations of Piping Plovers in the fall, and these were composed of no more than seven individuals. Roosting behavior was more frequently observed in the winter months. The three areas were used by roosting Piping Plovers in all three seasons were Galveston Island State Park (Segment 1), the beach in front of Pointe West development (Segment 7/8), and the beach on Segment 11 on Follet’s Island. Snowy Plovers were similarly encountered roosting more frequently in winter than in fall, and only on five occasions in the spring. Though they were occasionally encountered roosting with Piping Plovers at Galveston Island State Park and in front of Pointe West, most of the roosting concentrations of this species were on the west end of Segment 12 and up to 1 km west into Segment 13 on Follet’s Island.

In both study areas, roosting aggregations of plovers were typically encountered on parts of beaches with minimal disturbance, minor topographical relief (~6cm high ridges or furrows) and scattered debris including driftwood and decaying reeds and water hyacinth.

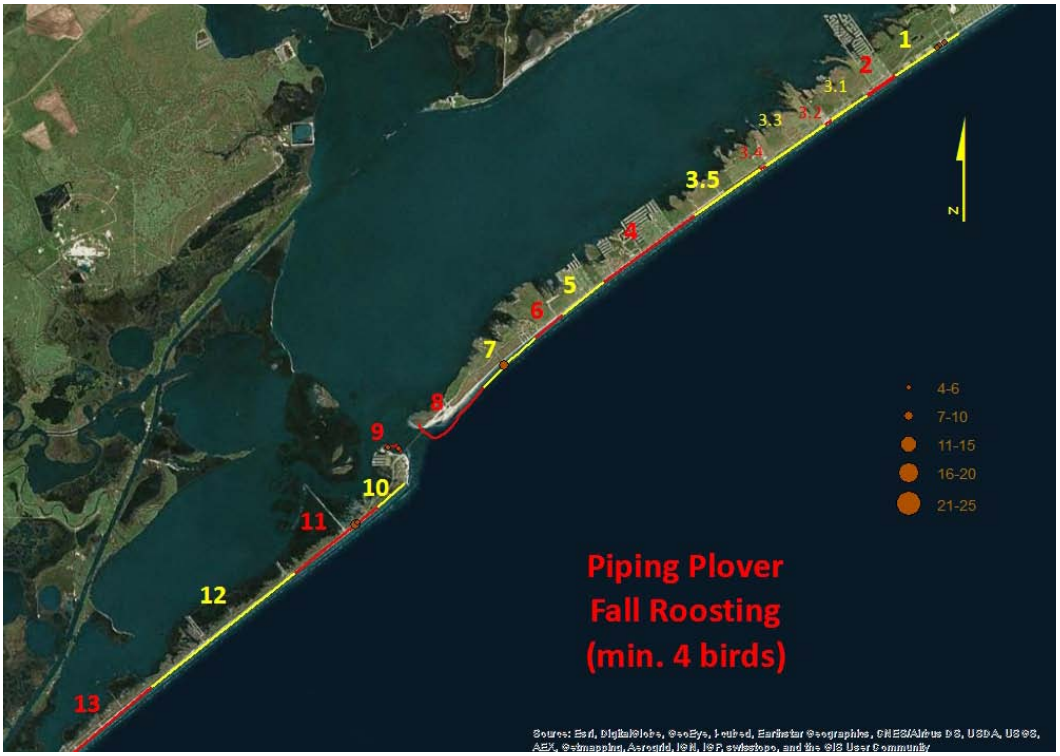

Figure 15. Points where 4 or more Piping Plovers were observed roosting during fall beach surveys in the Galveston Bay study area.

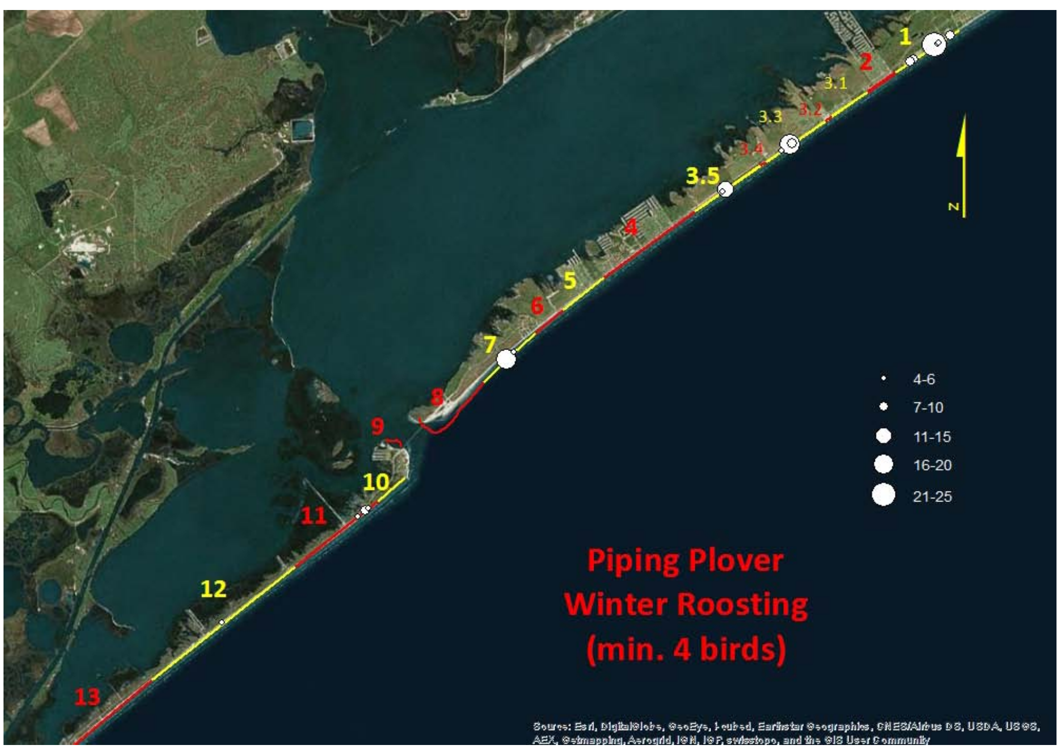

Figure 16. Points where 4 or more Piping Plovers were observed roosting during winter beach surveys in the Galveston Bay study area.

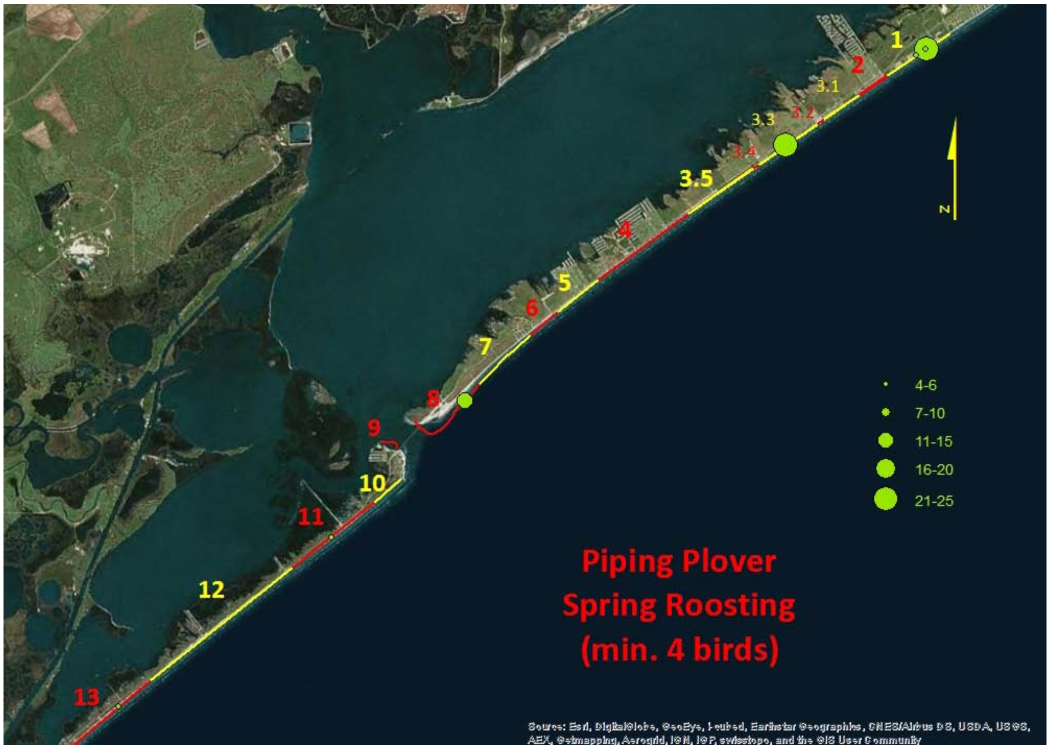

Figure 17. Points where 4 or more Piping Plovers were observed roosting during spring beach surveys in the Galveston Bay study area.

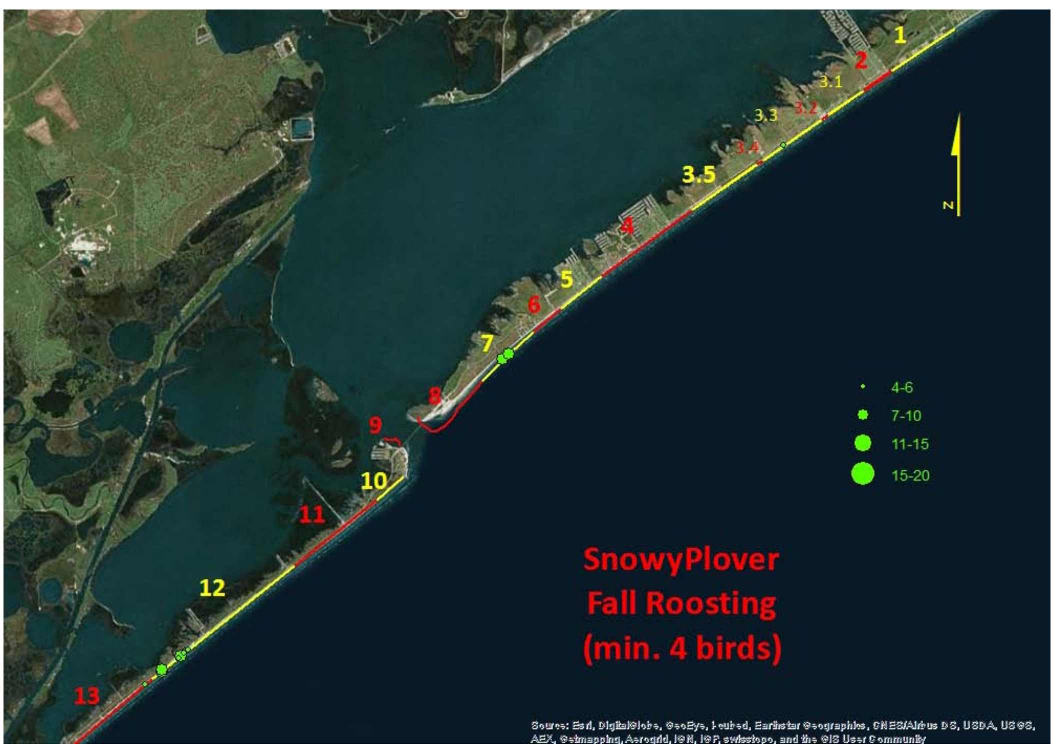

Figure 18. Points where 4 or more Snowy Plovers were observed roosting during fall beach surveys in the Galveston Bay study area.

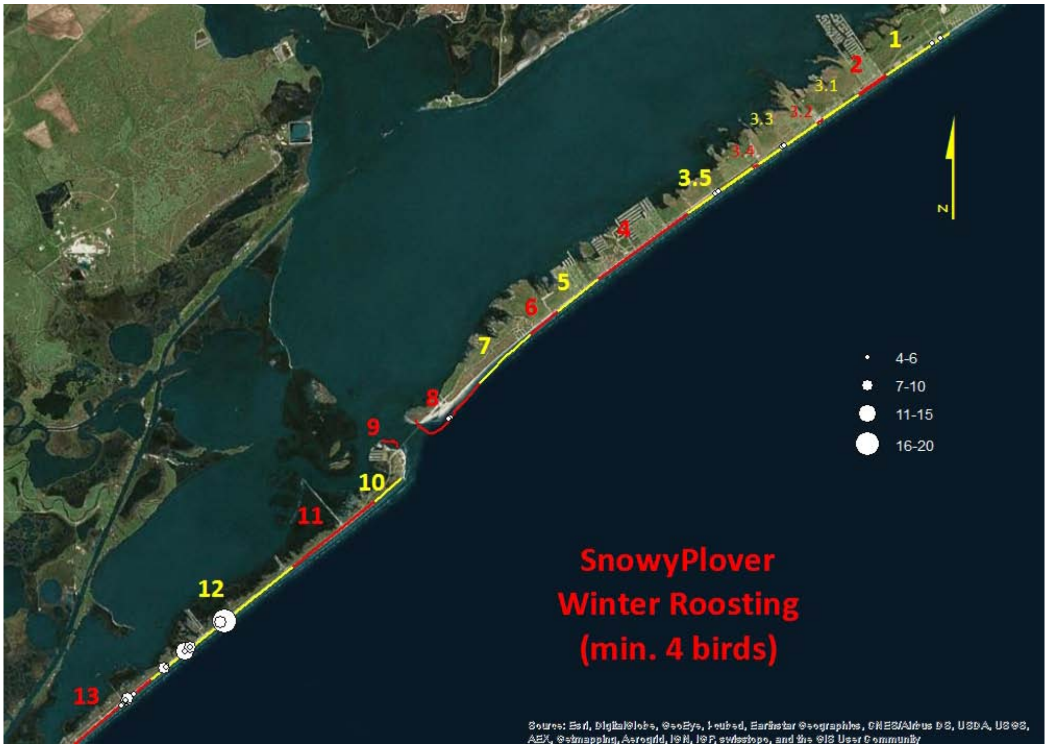

Figure 19. Points where 4 or more Snowy Plovers were observed roosting during winter beach surveys in the Galveston Bay study area.

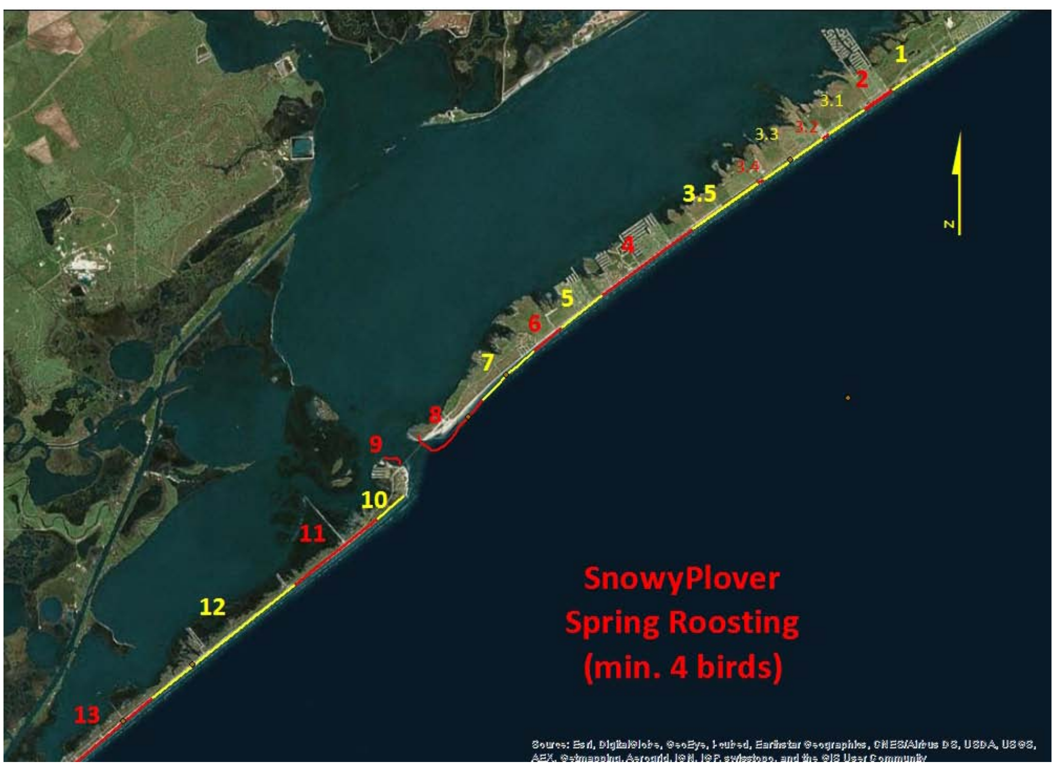

Figure 20. Points where 4 or more Snowy Plovers were observed roosting during fall beach surveys in the Galveston Bay study area.

DISCUSSION

Piping Plover densities were higher on North Padre and Mustang Islands in the fall, but lower in both winter and spring, whereas densities remained relatively consistent between seasons on Follet's and Galveston Islands. Data from another study (Newstead 2014) using radiotelemetry on birds captured on Padre Island suggests that high densities of Piping Plovers on beaches in the fall are composed partly of seasonal migrants which winter further south than this study area as well as overwintering birds. Patterns of movement in that study showed that overwintering birds transitioned from a habitat use pattern of primarily beach usage to one of mainly bay (Laguna Madre) usage in the winter as seasonal low tides expose vast sand and algal flats. Since the Laguna Madre is only weakly connected to lunar tide cycles experienced on the gulf beach, the tidal rise typically experienced in spring is often delayed in the Laguna Madre resulting in an extended period of exposure of flats for feeding prior to migration. This seasonal beach use pattern is consistent with that observed by Chapman (1984) in a study covering an area within this study area.

By contrast, San Luis Pass is a natural pass with a higher tidal prism and is maintained by natural dynamic processes. Tidal influence on the bayshore habitats of Follet's and Galveston Islands are characterized by a slight time lag and slightly lower amplitude as that of the gulf beach, but are still substantial enough to result in a tidal effect on availability of suitable foraging habitat. Alternation between gulf beach and bayshore habitat use during the midwinter period was typical of most of the birds from the radiotelemetry component of this study. It is also possible that a significant number of birds that winter further south begin to move north prior to migration resulting in higher spring densities in the Galveston area. Evidence for this from this study includes the two birds radiomarked by a separate project on Padre Island in the winter subsequently moved >250 up the coast into the Galveston study area. One of these assumed a habitat use pattern typical of birds captured in the San Luis Pass part of the study area, while the other was detected only one day on Bolivar Peninsula.

Snowy Plovers are resident year-round on the Texas coast, but the population is supplemented by an influx of birds associated with the interior breeding population beginning in fall. Tidal conditions as previously described probably similarly affect the fall and winter densities of this species on the beach. They are typically associated with Piping Plovers when encountered in winter, particularly in the Laguna Madre where feeding habitat is comprised mainly of vast sand and algal flats. Their timing of occurrence on gulf beaches also coincides with that of Piping Plovers. However, while Piping Plovers abundance was slightly lower in spring than in fall or winter in the Galveston study area, Snowy Plovers became were even less common on the beach surveys in spring. Resident Snowy Plovers may begin breeding as early as February or March in Texas, and the preferred nesting habitat is located primarily on the bayside shores of the barrier islands which may be partly responsible for lower densities on beach surveys. Additionally, the interior population of the species departs for breeding grounds by March or April, which would also contribute to an apparent decline in the spring surveys.

Both Piping and Snowy Plovers were encountered in high densities on Segments 5, 6 and 7 on North Padre Island in the fall with the exception of the northern kilometer of segment 5 (Kilometer S05). Mean Piping Plover density within Segment 6 was 86.9% and 95.4% higher than in adjacent Segments 5 and 7, respectively. Snowy Plover densities were 172.6% and 126.7% higher than in Segments 5 and 7. Curiously, not only was the mean density of all kilometers within Segment 6 higher than the other segments, but densities were higher in each individual kilometer of Segment 6 than all kilometers in either Segment 5 or 7. However, in winter surveys slightly higher densities were recorded in Segment 5 than in Segment 6, though in all cases the mean densities were lower in winter than in the fall surveys. As this and other projects (Newstead 2014) in the area have demonstrated, Piping Plovers use bayside habitats when they are available, and the most proximate sand and algal flats that provide habitat for Piping and Snowy Plovers near the beach survey area are on the Laguna Madre side of Segment 5, while there is little suitable shoreline on the Laguna Madre behind Segment 6. Newstead (2014) showed that all birds captured on the beach in Segment 5, and some from the northern end of Segment 6, divided habitat usage between the gulf beach and the large sand/algal flat most proximate to Segment 5. Human use patterns are somewhat different between these three segments but substantially lower than the high-use areas of Segments 3 and 4. No beach management activities are conducted on either 5, 6 or 7 with the exception of some minimal removal of *Sargassum* in front of the Malaquite Visitors Center on Segment 6. The other notable difference is that driving on the beach is not allowed by the public on Segment 6 with the exception of Park vehicles, researchers and sea turtle patrol staff.

While these are the first surveys we know of to cover these stretches of beach using this specific protocol, other comparable survey data exist that may provide insight into changes in distributions or populations over time. Chapman (1984) conducted weekly surveys from 3 October 1979 to 30 June 1981 on the 8.1 km stretch of beach of North Padre Island corresponding roughly to kilometers S06 to S14 of Segment 5 in this study, and reported mean densities per kilometer by month for several species including Piping and Snowy Plovers. While the pattern of high fall density followed by lower winter and lowest spring densities is consistent with this study, the density of birds was substantially lower in this study (Table 3).

	Chapman (1984)			This study			% change		
	Fall	Winter	Spring	Fall	Winter	Spring	Fall	Winter	Spring
Piping Plover	3.4	2.0	0.67	2.5	0.76	0.59	*-26.5*	*-62.0*	*-11.9*
Snowy Plover	1.8	1.0	0.4	0.82	0.39	0.05	*-54.4*	*-61.0*	*-87.5*

Table 3. Comparison of mean seasonal density (birds per kilometer) between Chapman (1984) and this study on Segment 5 (North Padre Island).

Relatively little has changed with regard to the types of activities occurring on this stretch of beach in the intervening three decades though the intensity of use likely increased over that time primarily in the northern edge of the area. It is unclear whether this apparent decline reflects a true population decline or some other impact to the habitat, or a combination of these. The previous study was conducted partly in response to the Ixtoc I oil spill in the southern Gulf of Mexico which resulted in moderate to heavy oiling of most of south Texas beaches beginning in August 1979. The oil persisted on the beaches until late in September when high tides and wave activity associated with two tropical storms pushed the stranded oil up to the foredunes or buried it in sand. A 70% reduction in total individuals of the infaunal community was documented by Kindinger (1981) following the oil spill. It is possible that factors such as reduced food availability, sublethal chronic effects of oil exposure, or other ecological consequences may have negatively affected birds following the oil spill. Without other comparable surveys conducted using similar methodology between that study and this one, it is not possible to ascertain the timing or magnitude of this apparent decline.

Elliott (1996) conducted a study on the effects of human disturbance on Piping Plovers at three sites in the central Texas coast, two of which lie within the boundaries of the Corpus Christi study area beach survey route. One of these, "Malaquite," involved a 1.9 km segment of our segment 6 which corresponds approximately to kilometers 22 and 23 of our route. The other, "Surfer Beach," corresponds directly with Segment 3. While the study was primarily focused on interactions between Piping Plovers, humans and vehicles, ancillary data included quantification of the number of individuals per kilometer. Those data are not statistically comparable with this study because the frequency and duration of the surveys in that study were not similar (frequency was variable but spanned all three nonbreeding seasons of three years fall 1993 – spring 1996). However, the reported densities from that study are of note. Data from the Elliott (1996) study would indicate that Piping Plovers have declined 69.6% and 58.5% at Segment 3 (Elliott's "Surfer Beach") and kilometers S22-S23 (Elliott's "Malaquite"), and Snowy Plovers have declined by 30.5 and 47.8%, respectively (Table 4). By contrast, human and vehicle presence at "Surfer Beach" are considerably larger in this study. Indeed, the beach has changed significantly in the intervening two decades, including the dredging of Packery Channel and installation of rock jetties and a considerable increase in the amount of residential and commercial development on Padre Island and population increase throughout the south Texas region.

Site		Elliott (1996)	This study	% change
Segment 3	Piping Plover	3.1 (37.6)	0.96 (23.0)	-69.6
"Surfer Beach"	Snowy Plover	0.6 (5.9)	0.41 (13.0)	-28.8
	Humans	2.2 (30.0)	9.3 (25.9)	317.0
	Vehicles	3.1 (37.8)	6.7 (13.3)	117.5
S22-S23 km	Piping Plover	4.5 (15.3)	1.87 (8.5)	-58.4
"Malaquite"	Snowy Plover	1.8 (7.4)	0.96 (5.0)	-46.7
	Humans	2.6 (26.3)	*2.3 (7.1)*[a]	*-11.2*[b]
	Vehicles	0.1 (1.0)	*0.1 (0.4)*[a]	*-14.3*[b]

Table 4. Comparison of mean densities (followed by maximum densities in parentheses) of plovers and human disturbance factors at two sites surveyed during this study and a previous study (Elliott 1996). Elliott's "Malaquite" site is approximately analogous to kilometers S22 –S23 in this study. [a] Human disturbance factors for this study are based on the full segment length (8.3 km). Since the "Malaquite" site from Elliott (1996) was focused on the area of highest density of human (pedestrian) visitation the actual densities on that stretch during this study were likely substantially higher than those used as the basis for comparison.

Elliott (1996) found that birds encountering pedestrians spent significantly less time in foraging behavior than active nonforaging behavior. There was also negative correlation between the number of vehicles and Piping Plover density on "Surfer Beach," but while number of people and number of vehicles were highly correlated the correlation between number of people and Piping Plovers was nonsignificant. This might indicate that the densities of humans and vehicles on the beach during that study were not high enough to strongly influence plover distribution. Assuming that increased interaction with humans and vehicles would result in even less time available for foraging, it is logical to surmise that beyond some unknown level of density the beach becomes unsuitable as habitat since calorie expenditure would eventually exceed calorie acquisition. The effects of beach management practices may also play a role in the quality of the habitat. Throughout the southern three kilometers of Segment 3, removal of natural debris and *Sargassum* was intensive during this study, with heavy equipment frequently redistributing and grooming sand across the width of the beach and down to the shore.

Changes in human use at "Malaquite" appear to be minimal but may be significantly larger in a positive direction than the comparisons made in Table 4 suggest. The basis of the density for these factors in this study is the entire Segment 6. The 1.9 km segment surveyed in Elliott (1996) was immediately in front of the Malaquite Beach Visitors Center and campground, which is the area where the vast majority of visitors are concentrated within the 8.3 km segment. Very few pedestrians venture far north of the site surveyed by Elliott, so the actual density at kilometers S22 and S23 would likely have been considerably higher than those reported here for all of Segment 6.

Another study (Zonick 2000) reported densities of Piping Plovers at sites corresponding to Segments 1, 2 and 3 of this study on Mustang Island in the Corpus Christi study area, based on surveys conducted throughout the nonbreeding season. Comparison between that study and this one provides further evidence that Piping Plover density has declined throughout the area, and especially in Segment 3 (Table 5).

Site	Zonick (2000)	This study	% change
Segment 1	3.22	1.49	-53.7
Segment 2	3.26	1.44	-55.8
Segment 3	3.59	0.95	-73.5

Table 5. Comparison of mean densities of Piping Plovers (birds/km) at beach survey sites surveyed during this study and a previous study which surveyed in years 1991-1994 (Zonick 2000).

Foster et al 2009 report a marginally significant 25.4% decline in Piping Plovers between 1979 and 2007 on the 11.9 km stretch of beach immediately north of our Segment 1 on Mustang Island, while the decline in Snowy Plovers was small (3.6%) and nonsignificant. The number of people and vehicles increased 449.6% and 82.0% over that same period. They postulated that declines in bird abundance could be associated with either birds' winter range shifting – in which case an increase may be detected in other areas – or with broader-scale population declines. Based on comparison between this study and Elliott (1996) and Chapman (1984) which surveyed some of the same areas, trends in abundance mirror those documented by Foster et al (2009). There is no evidence that these species' ranges have shifted to the 43 km stretch of beach south of their study area (under which scenario densities should have increased in ours), so unless they have shifted a much greater distance outside the study area there seems to be strong evidence of a broader population decline but it is unclear from these data whether the decline is regional in nature (the wintering population in the study area) or at the scale of the entire Northern Great Plains breeding population. If the decline is isolated to the south Texas portion of this study area, then the area may be becoming, or already is, a population sink.

Recommendations

The beach survey component of this study raises concern regarding the possibility that populations of birds wintering in the Corpus Christi Bay study area are declining at a rate exceeding that of the Northern Great Plains population as a whole. Four mortalities of Piping Plovers were documented during the duration of this project, including two birds that were part of the study (see Appendix 4). Of the four mortalities, only one appears to have been likely due to a natural cause (avian predation). The two deceased birds that were not part of this study were both individually marked, so it is possible that even these would have been bypassed and not brought to our attention if not for the discoverers' (both wildlife professionals) recognition that the information could be specifically useful to researchers. Aside from direct mortalities, the effects of human disturbance and beach management may be affecting bird distributions and individual bird fitness which could also have survival consequences. The rapid rate at which human recreational use of Gulf beaches is increasing in the Corpus Christi area is likely to further affect usage of beaches by Piping Plovers and other shorebirds, eventually decreasing the capacity of the area to support robust populations. In both study areas, all uniquely marked Piping Plovers encountered either on beach surveys or during telemetry efforts were recorded and will be reported to the appropriate bander (many already have). By analyzing mark/resight data from breeding and wintering grounds, it may be possible to detect differences in survival based on wintering area.

Further efforts will be made with data collected in these and other surveys to determine the relative contribution of specific factors that may be limiting beach usage by Piping Plovers. Since recreational beaches are managed for people, people are attracted to them, and they generally arrive in vehicles, so beach management, human, and vehicle density are almost always autocorrelated. Further data collection and regression analysis, and comparison with other areas, is needed to elucidate factors that affect Piping Plovers and determine what possible conservation actions can be taken to limit further negative effects. Entities responsible for permitting beach management activities by municipalities should take a precautionary approach to approving activities that are likely to substantially alter natural beach processes.

Acknowledgments

In addition to funding for this project, US Fish & Wildlife Service provided assistance with trapping activities and beach surveys, and provided copies of difficult-to-find literature and reports that helped inform the project. Staff with National Park Service facilitated access to Padre Island National Seashore for beach surveys. Texas Parks & Wildlife Department facilitated access to Mustang Island State Park and Galveston Island State Park for trapping, telemetry and beach surveys. Houston Audubon Society provided access to the Bolivar Flats Shorebird Sanctuary for trapping and telemetry. Additional logistical and financial support was provided by Environmental Institute of Houston at University of Houston-Clear Lake.

Literature cited

Arvin, J. 2010. A survey of Upper Texas Coast critical habitats for migratory and wintering Piping Plover and associated resident "sand" plovers, Final Report. Report to Texas Parks & Wildlife Department and US Fish & Wildlife Service. 25 pp.

Chapman, B.R. 1984. Seasonal abundance and habitat-use patterns of coastal bird populations on Padre and Mustang Island barrier beaches (following the Ixtoc I oil spill). US Fish & Wildlife Service. FWS/OBS-83/31. 73 pp.

Cohen, J.B., S.M. Karpanty, D.H. Catlin, J.D. Fraser and R.A. Fischer. 2008. Winter ecology of Piping Plovers at Oregon Inlet, North Carolina. Waterbirds 31(3):472-479.

Cowardin. L.M., V. Carter, F.C. Golet and E.T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. US Department of the Interior, Fish and Wildlife Service, Washington, D.C. 131 pp.

Drake, K.R., J.E. Thompson, K.L. Drake and C. Zonick. 2001. Movements, habitat use, and survival of nonbreeding Piping Plovers. Condor 103:259-267.

Elliott, L.F. 1996. Effects of human disturbance on threatened wintering shorebirds. Final report to Texas Parks & Wildlife Department, Section 6 Grant Number E-1-8, Project 53. 10 pp.

Foster, C.R., A.F. Amos and L.A. Fuiman. 2009. Trends in abundance of coastal birds and human activity on a Texas barrier island over three decades. Estuaries and Coasts 32:1079-1089.

Kindinger, M.E. 1981. Impact of the Ixtoc I l spill on the community structure of intertidal and subtidal fauna along south Texas beaches. M.S. Thesis. Corpus Christi State University, Texas. 91pp.

Newstead, D.J. 2014. Habitat use of North Padre Island and Laguna Madre habitats by Piping Plovers (*Charadrius melodus*) and Red Knots (*Calidris canutus*) in the vicinity of current and proposed wind energy development. Final report to Texas Parks & Wildlife Department, Section 6 Grant Number E-137-R, Project 53. 27pp. plus appendices.

Texas Coastal Ocean Observation Network. Website accessed 2012. Division of Nearshore Research, Conrad Blucher Institute for Surveying and Science,Texas A&M University – Corpus Christi.

U.S. Fish & Wildlife Service. 2009. National Wetlands Inventory website. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C. http://www.fws.gov/wetlands.

Zonick, C., Katherine Drake, Kiel Drake, L. Elliott and J. Thompson. 1998. The effects of dredged material on Piping Plovers (*Charadrius melodus*) and Snowy Plovers (*Charadrius alexandrinus*) in the Lower Laguna Madre of Texas, Final Report (1997/1998 Season). Report to Texas Parks & Wildlife Department and US Fish & Wildlife Service. 15 pp.