UNIVERSITY OF MINNESOTA

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Date

WINTER DISTRIBUTION OF PIPING PLOVERS ON THE U.S. GULF OF MEXICO: AN ANALYSIS OF HABITAT CHARACTERISTICS AT MAJOR WINTERING SITES

A THESIS SUBMITTED TO THE FACULTY OF THE GRADUATE SCHOOL OF THE UNIVERSITY OF MINNESOTA
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ABSTRACT

Piping Plover (*Charadrius melodus*) populations have been federally listed as endangered or threatened in the U.S. for 19 years, but recovery efforts have been unable to remove the species from imperiled status. Although most protective efforts focus on plovers while they are on the breeding grounds, greater attention is warranted during the non-breeding period because >75% of the annual cycle occurs during migration and winter; quality and quantity of wintering habitat are known to be important for wintering shorebirds. This study was conducted, at the major wintering sites of Piping Plovers along the U.S. Gulf of Mexico coast, the final destination for most wintering Piping Plovers, to identify key features of the sites that favor or discourage use by plovers. To identify important winter sites for Piping Plovers, I reviewed published records of winter plover surveys to identify important wintering locations and visited a subset of those sites to record habitat features. Piping Plovers consistently winter at 49 locations on the U.S. Gulf of Mexico coast (Marco Island, FL to Padre Island, TX); at 25 locations, Piping Plovers occur in high abundances (≥30 individuals). To further understand the landscape features of confirmed wintering sites, I delineated a 3.5km area around Piping Plover observations and conducted a remote analysis of aerial photos for 11 geomorphological (e.g. inter-tidal area, beach area) and human infrastructure (e.g. urban area, roads) characteristics. Linear regressions were used to test correlations between plover abundance and landscape characteristics. I found that Piping Plover abundance was positively correlated with inter-tidal area, inter-tidal and beach area, and peninsula/island landforms. In contrast, plover abundance was negatively correlated with urban area and road length. I used these relationships to parameterize a model that predicts the abundance of Piping Plovers across the Gulf of Mexico coast. The model, incorporating landform category, inter-tidal area, and urban area, explains 46% of the variability in Piping Plover abundance on the entire coast (df=30, adjusted R-squared: 0.4621; p = 0.00018). This study found a relationship between plovers and habitat features demonstrating that both land-formations and urbanization influence the distribution and abundance of Piping Plovers wintering on the U.S. Gulf of Mexico Coast. This information is critical for land managers in the Gulf region as they develop and implement policy in rapidly changing coastal ecosystems.

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“The future of many species of migratory shorebirds depends on adequate conservation of relatively few wintering and staging sites… at present the small wetland wintering and staging sites are most under pressure from ever expanding humanity” (Piersma and Baker 2000).

I. Introduction

There is increasing evidence that shorebirds are in decline (Howe et al., 1989; Morrison et al., 1994; Brown et al., 2000; Morrison et al., 2001). Out of a total of 74 shorebird taxa (e.g. species, subspecies, populations) that breed in the U.S. and Canada, seven are considered “highly imperiled” and 23 have status of high concern (U.S. Shorebird Conservation Plan, 2004). As migratory organisms, shorebirds are seasonal residents and their continued presence indicates condition of suitable habitats both locally and throughout their annual range. Seasonal variations and/or scarcity of resources force shorebirds to over fly large stretches of unsuitable land and ocean to reach breeding and wintering sites (Alerstam, 1990; Williams and Williams, 1990). Although long flights expose shorebirds to many risks during migration, studies indicate that degradation or complete loss of wintering habitat may also play an extremely important role in shorebird survival (Goss-Custard et al., 1995; Durell et al., 1997). For example, loss of habitat on the wintering grounds has been implicated in the decline of several species (e.g. Eskimo Curlew (*Numenius borealis*), Pacific Golden Plover (*Pluvialis fulva*), Red Knot (*Calidris canutus*), Slender-billed Curlew (*Numenius tenuirostris*).

Although winter ecology for most shorebirds is poorly known, research demonstrates that this group, in general, shows high site tenacity to specific winter locations both within and between seasons (Evans, 1981). Additionally, wintering sites are often very small, but are occupied by large concentrations of birds. These observations provide strong evidence that shorebirds are drawn to specific locations on the landscape that meet their winter survival requirements. Therefore, loss or deterioration of these sites has the potential to significantly limit shorebird populations, particularly when coastal change is viewed from a landscape perspective. Over the past half century, the most rapidly developed ecosystems in the world have been those found in coastal regions (Brown and McLachlan, 2002). Furthermore, demographic projections indicate continued increases in coastal development. Currently, more than half the U.S. population lives in the coastal areas that comprise < 20% of U.S. land mass (National Research Council, 2000) and the rate of coastal urbanization is increasing (U.S. Census Bureau, 2003).

This study investigates the relationship between a highly imperiled species, the Piping Plover (*Charadrius melodus*) and the characteristics of its regional winter habitat. Piping Plovers spend approximately two-thirds of their annual cycle on the wintering grounds. They arrive at these sites between late July and September and remain until northward migration peaks in late March and is almost complete by late May (Eubanks, 1994). Although genetic and behavioral observations recognize that the three breeding populations (Northern Great Plains, the Great Lakes, and the Atlantic Coast) are geographically and biologically distinct (Haig, 1992), all three populations winter in the same area: coastal U.S. from Texas to North Carolina, eastern Mexico, and the Caribbean islands—from Barbados to Cuba and the Bahamas (Haig, 1992). International Piping Plover winter censuses have documented that the majority of wintering individuals reside on the Gulf of Mexico coast (Haig and Plissner, 1993; Plissner and Haig, 2000; Ferland

and Haig, 2002). Research demonstrates that Piping Plovers exhibit wintering ground site fidelity (Eubanks, 1994; Wemmer, 2000; Drake et al., 2001) thus, confirming the importance of site specific habitat protection for this species. My goal was to identify key features of winter sites that favor or discourage use by plovers. This information is critical for land managers in the Gulf region as they develop and implement policy in rapidly changing coastal ecosystems.

Despite almost two decades of intense conservation programs, threats to Piping Plovers remain substantial throughout their annual cycle. USFWS (2001) lists several factors threatening wintering habitat: recreational activities, inlet and shoreline stabilization, dredging of inlets, beach maintenance, and pollution. Designation of winter critical habitat in 2001 emphasizes that Piping Plovers are gradually losing significant portions of their historic wintering habitat to land conversion and degradation (USFWS, 2001). Although designation of critical habitat was a significant action in favor of their protection, more information on winter ecology is needed to understand site preferences and to ultimately support species-wide recovery.

Studies of landscape-level features that influence the distribution and abundance of Gulf Coast wintering Piping Plovers are either dated or limited. Since completion of earlier landscape habitat studies (Johnson and Baldassarre, 1988; Nicholls and Baldassarre, 1990a; Nicholls and Baldassarre, 1990b), new research has contributed to knowledge of plover winter ecology: e.g., winter site fidelity (Eubanks, 1994), disturbance (Burger, 1991; Burger, 1994; Zonick and Ryan, 1995), home range and habitat use (Drake et al.,

2001) and winter censuses (Haig and Plissner, 1993; Plissner and Haig, 2000; Ferland and Haig, 2002).

To understand the relationship between coastal habitat and wintering plovers, I studied habitat quality, human infrastructure, and the distribution and abundance of wintering Piping Plovers. The objectives of my study were to identify current Piping Plover wintering sites on the Gulf of Mexico coastline, survey a sample of sites on the Gulf Coast, and conduct a remote landscape analysis of winter habitat characteristics to identify key features that favor or discourage plover use of these sites. I predicted that plover abundance would be positively correlated with inter-tidal and associated landforms and negatively correlated with human infrastructure.

II. Methods

Study Area:

My study area included portions of the U.S. Gulf of Mexico coastline from Marco Island, FL to South Padre Island, TX (Figure 1). Five geomorphological regions characterize the coastline (USFWS 1982):

Texas Barrier Island System

The Texas Barrier Island System extends from Galveston Bay south-southwest to Brownsville, TX. Lagoons and bays, primarily Galveston Bay and the Laguna Madre, are bordered by barrier islands. From Galveston (upper coast) to Corpus Christi (mid-lower coast), numerous southeasterly flowing streams contribute freshwater inflow to marsh systems. From Corpus Christi to Brownsville, the combination of minimal freshwater inflow, protection by barrier islands, low runoff, and high evaporation rates produce hyper-saline conditions. Bays in this region are shallow; slight changes in water level can expose or inundate large areas of coastal flats.

Mississippi Delta

This geomorphological region extends from Petit Bois Pas west to Vermillion Bay, LA. The dominant landform is the "bird-foot" delta which is composed of extensive, shallow areas. It features a marsh and barrier island system, shallow lakes, bayous, and stream channels. The Mississippi and Atchafalaya rivers influence the silt load of the delta; the former contributes an especially large silt load to the delta.

North Central Gulf Coast

The North Central Gulf Coast extends from Cape San Blas, FL, to Petit Bois Pass, on the Alabama/Mississippi border. Bay and sounds, primarily Perdido Bay, Wolf Bay, Little Lagoon, and Mobile Bay, are protected by barrier islands. High-energy sandy beaches and extensive dunes intersperse the bays and sounds.

Apalachicola Cuspate Delta

The Apalachicola Cuspate Delta extends from Lighthouse Point west to Cape San Blas. Coastlines and bays are protected by smooth, sandy barrier islands. The Apalachicola, Flint, Chattahoochee, and Chipola rivers contribute freshwater to the bay; hence, bays have turbid water and muddy bottoms.

Central Barrier Coast

The Central Barrier Coast is a transition zone between north and south Florida that extends from Cape Romano north to Tarpon Springs, FL. In this region, a series of barrier islands protect shallow embayments and the landscape consists of exposed sandy beaches and extensive marshy/swampy areas; occasional mangrove stands and rocky areas also occur.

Identifying Current Piping Plover Wintering Sites

To identify sites important to Piping Plovers wintering along the U.S. Gulf of Mexico, I compiled records of wintering (December-February) plovers from sources published between 1871 and 2003. To identify current wintering sites, I only considered records published between 1991 and 2003; older records were used to identify sites of historic plover usage. These records included: Christmas Bird Counts, Natural Heritage Program records, the International Piping Plover Censuses (1991, 1996, 2001), Audubon Field Notes, and state bird journals. Locations that were ill-defined (e.g. an entire county) were excluded. The term “site” refers to a geographic location of beach and/or tidal areas that is historically referenced and delineated in the literature.

For each record, the location, year, estimated number of Piping Plovers present, and data source were entered into a searchable Excel database (Microsoft, 2002). Because my objective was to identify consistently used wintering sites, I grouped number of plovers present into three categories (1-14, 15-29, and 30 or greater individuals) to reduce the influence of sporadic reports. For each site, priority was given to the highest recorded abundance; if at least two estimates fell into a category, then the site was considered to be a confirmed wintering site at that abundance level.

Visits to Selected Piping Plover Wintering Sites

I visited and conducted surveys at a subset of current plover wintering sites from January to March 2004 to supplement plover records, document other co-occurring plover species, gain familiarity with habitat features of individual sites, and gauge recreational activity at all locations. Knowledge from these visits was used to increase the accuracy of the GIS analysis. Survey locations were selected from wintering sites identified through the literature search. Based on accessibility, a subset of 21 current wintering sites was visited. At each site, I traveled (by foot, bicycle, car, or boat) the length of the beach or inter-tidal flat and counted the total number of Piping Plovers I observed. Because shorebirds forage in response to tidal conditions (Evans, 1976), surveys were coordinated with tide schedules. Beaches were surveyed at high tide and flats at low tide. Surveys were performed without preference for weekday or weekend. Total plover abundance, GPS location, abundance of other *Charadrius* plovers (i.e. Snowy Plover, *Charadrius alexandrinus;* Wilson's Plover, *C. wilsonia;* Semipalmated Plover, *C. semipalmatus*), substrate, and evidence of human activity (e.g. tire tracks, footprints) were recorded. The mean Piping Plover count, maximum count, and variance were calculated for each site in Excel (Microsoft, 2002). These data provided additional information about local abundance, substrate preferences, and presence of human activity.

To increase accuracy of ground-to-image comparison for GIS analysis, I recorded the substrate type at a subset of the 21 sites visited. Substrate was placed in one or more of the following categories: lower beach, upper beach, mudflat, sandflat, sand-mudflat, lagoon (Nicholls and Baldassarre, 1990b). Finally, a GPS location was recorded for plover observations; if multiple plovers were observed, the highest concentration was recorded. No formal analyses were performed with the habitat information from these visits, but my observations permitted comparison between the recorded substrate and aerial photographs.

Measuring Habitat Variables at Piping Plover Wintering Sites Using Remote Sensing

To determine the relationship between Piping Plovers and the characteristics and quantity of their wintering habitat, I included all consistently used wintering sites with geo-referenced plover locations (Geographic Positioning System coordinates or records referencing a unique landform) in a GIS analysis of landscape features. Thirty-one sites on the Gulf of Mexico coast met these criteria (Table 1, Figure 1).

Due to widespread availability, minimal cost, and high quality, Digital Orthographic Quads (DOQQs) were chosen as the base image for the landscape analysis. Recent (1994-1999) DOQQ images were acquired from four sources: Texas Strategic

Mapping Program, ATLAS: The Louisiana Statewide GIS, Land Boundary Information System (Labins), and Alabama State Water Program (e.g. Figure 2). The images were imported into ArcMap 8.3 (ESRI) and all spatial layers were overlain on the DOQQ images. To begin, Piping Plover locations were obtained from multiple sources: personal observations, USFWS, Louisiana Natural Heritage Program, and Stucker et al. (2003) (Table 2). Using ArcTools (ESRI, 2002), the Piping Plover observations (GPS point or descriptive location) were manually superimposed onto DOQQ images. For sites with multiple reported observations, the most recent observation with the maximum abundance was used for the analysis.

Next, using spatial analysis tools in ArcMap (ESRI, 2002), the plover geo-referenced point for each site was buffered at a radius of 3.5 km (e.g. Figure 3). This radius was selected because (Drake et al., 2001) reported that 50% of winter movements occurred within a 2.9 km^2 core area in coastal Texas. These investigators also found that the mean linear distance moved by wintering plovers was 3.3km (Drake et al., 2001). Only the area within the buffer zone was considered for further analysis.

For each site, the DOQQs were analyzed for 10 habitat parameters to determine if plover abundance was correlated with specific habitat or anthropogenic variable. Four features were manually digitized at a 1:6,000 scale: inter-tidal area (emergent and submerged), beach, lagoon, and river (e.g. Figure 4). To improve accuracy, I compared the DOQQs to corresponding features in updated 4 m Digital Raster Graphics (DRGs); the DRGs provided additional information on tidal and marine zones, thus facilitating photointerpretation (e.g. Figure 5). The most recent demographic data were acquired from multiple sources: U.S. Census Bureau, TX Parks and Wildlife Division, TX General Land Office, TX Department of Transportation, and the Louisiana Oil Spill Coordinator's Office. Four anthropogenic variables were overlain on the study site: urban area, primary roads, beach access points, and marinas/boat launches. To quantify the habitat characteristics for statistical analysis, I calculated 10 parameters for each site: area (inter-tidal, beach, inter-tidal and beach, lagoon, urban), length (river, roads), perimeter (lagoon), and the number (beach access points, marinas/boat launches) with Spatial Analyst Tools in ArcMap 8.3 (ESRI, 2002). I also recorded whether the location was a peninsula/island form or on the mainland.

Statistical Analysis

To evaluate the relationship between plover abundance and the landscape data acquired from the GIS analysis, statistical analyses were performed with the software package R (2004, The R Foundation for Statistical Computing, Version 1.9.1). High quality censuses are generally unavailable for most species; however, the International Piping Plover census is an exception. Every five years, volunteers visit delineated areas and follow specific guidelines for reporting observations. Because of the continuity and consistency, the censuses provide valuable data on abundance. Therefore, I compared the 11 habitat parameters acquired from GIS analysis with the mean count (all three census years) of the International Piping Plover Census (Haig and Plissner, 1993; Plissner and Haig, 2000; Ferland and Haig, 2002). To help meet assumptions of normality, I used the square-root transformation of the mean count. Scatter plots were examined to verify the linearity of relationships. Simple linear regressions were performed for each independent variable (area: inter-tidal, beach, lagoon, urban, total area; length: river, roads; perimeter: lagoon, number: beach access points, marinas/boat launches; category: mainland or peninsula/island) against the transformed mean count. When plover abundance was found to be significantly correlated with a parameter, the parameter was then input into multiple linear regression models. The most parsimonious model with the most explanatory power was selected as the final model.

III. Results

Current Piping Plover Wintering Sites

Using recent winter site use records, I identified 49 locations consistently used by Piping Plovers wintering on the Gulf of Mexico coast since 1991. All sites had records of multiple plover observations during the previous 14 years. Twenty-five sites had records indicating high abundances of wintering birds (e.g. Padre Island, TX and Bolivar Flats, TX) (Table 3). Moderate abundance was recorded at eight locations (e.g. Belle Pass, LA and Caladesi Island, FL) (Table 4) and low abundance at 16 locations (e.g. Holly Beach, LA and Cape San Blas, FL) (Table 5).

Winter 2004 Survey

During the winter 2004 survey, I observed 564 Piping Plovers in Texas and Florida (Figure 6). The minimum, non-zero count was one individual (site counts: n=3, SD=0.6) at Quintana/Bryan Beach, TX. The maximum count was 189 individuals at Bolivar Flats, TX (n=3, SD=72.2). Piping Plovers were not observed at six sites: Shell Island, FL; Eglin Beach, FL, Crooked Island, FL, Rockefeller National Wildlife Refuge, LA; Mustang Island, TX; Crystal Beach, TX. The majority of birds, 78%, were on the Texas Coast; the remaining 22% were located in Florida. Fifty-percent of counts recorded other plover species (Snowy Plover, *Charadrius alexandrinus,* Wilson's Plover, *C. wilsonia,* and Semipalmated Plover, *C. semipalmatus*) co-occurring with Piping Plovers.

Remote Analysis of Piping Plover Wintering Sites

Of the 11 ecological parameters measured by remote sensing, five were found to significantly predict Piping Plover abundance on the Gulf of Mexico coast (Table 6). Piping Plover abundance was negatively correlated with two parameters: urban area (df= 30, p=0.011) (Figure 7) and total road length (df=30, p= 0.049) (Figure 8). In contrast, inter-tidal area (df=30, p= 0.013) (Figure 9), mainland category (df=30, p= 0.0011) (Figure 10), and total inter-tidal and beach area (df= 30, p=0.013) (Figure 11) were positively correlated with plover abundance.

To understand how multiple habitat features influence Piping Plover abundance, parameters identified as significant in the initial analysis were incorporated into multiple linear regression models for the entire Gulf Coast. The most parsimonious model that explained the most variability in Piping Plover abundance incorporated three parameters:

inter-tidal area, urban area, and mainland category. The model—{y = sqrt (PIPL) ~ mainland category+ inter-tidal flat + urban}explains 46% of the variability in Piping Plover abundance on the entire coast (df=30, adjusted R-squared: 0.4621; p = 0.00018). To test for regional differences (e.g. inter-tidal area, beach management), I performed an ANCOVA with the software package R (2004, The R Foundation for Statistical Computing, Version 1.9.1). I subdivided the analysis into two regions: the western gulf coast (Texas, Louisiana, Alabama) and the eastern gulf coast (Florida). Differences between the western and eastern coastline were not statistically significant.

IV. Discussion

Current wintering sites

Piping Plovers are winter residents at numerous locations on the Gulf of Mexico coastline; in the U.S., they are consistently observed wintering from South Padre Island, Texas to Marco Island, Florida. Haig and Oring (1985) first attempted to delineate the species' winter range; surveys in the early 1980's recorded plovers wintering from Campeche, Mexico to Tampa, Florida. Additional studies (Nicholls and Baldassarre, 1990a; Nicholls and Baldassarre, 1990b) and the international censuses (Haig and Plissner, 1993; Plissner and Haig, 2000; Ferland and Haig, 2002) reiterated the importance of the Gulf of Mexico coast to wintering plovers. These earlier investigations also found that plovers consistently wintered in specific locations. My literature review supports these earlier conclusions, but suggests that more surveys are warranted at two locations: Redfish Bay (Port Aransas and Aransas Pass, Texas) and San Bernard National

Wildlife Refuge. Winter 2004 surveys indicate that more plovers winter in both locations than previously considered.

Ornithological records provide a wealth of information on historic and current trends in populations; records of wintering Piping Plovers date back 1871 at Miami, Florida (Howell, 1932). The literature review documented that plovers consistently winter at almost 50 sites on the U.S. Gulf of Mexico Coast. Texas and Florida host 48 % and 24 % of the high abundance (30 or more plovers) sites, respectively. Also, I found that historic records also implicate local declines in Piping Plovers. Records from 1900 to 1990 (Christmas Bird Counts) suggest that wintering plovers were observed for decades at six sites on the Gulf of Mexico Coast, but between the 1970's and 1980's, Piping Plovers were no longer reported from those locations. The six sites are (record high, last observed number, last observed year): Cocoa, FL (88, 2, 1988); Merritt Island N.W.R., FL(4, 1, 1977); Sarasota, FL (8, 6, 1982); Panacea, FL (30, 19, 1972); Pensacola, FL (14, 1, 1989); Mobile, AL (11, 1, 1976). Because indices may generate spurious results (Anderson, 2001), the records do not necessarily indicate local decline; however, they do suggest that certain localities warrant more investigation. Ornithological records link contemporary research with species history; successful, long-term management requires understanding of the "historical context of areas" that supported shorebirds in the past (Brown et al., 2001).

Winter surveys

During the winter 2004 survey, I recorded almost 80 % of Piping Plovers on the Texas coastline. International Piping Plover census results reported that 44 to 85 % of wintering plovers reside on the Mexican and U.S. Gulf of Mexico coastline (Haig and Plissner, 1993; Plissner and Haig, 2000; Ferland and Haig, 2002); the majority are found in Texas. Piping Plovers were often in the presence of other plovers, namely the imperiled Snowy Plover (*Charadrius alexandrinus*). Similarly, 81 % of the Piping Plovers observed by Nicholls and Baldassarre (1990a) were in the presence of > 5 other shorebird species. These observations endorse the benefit of multiple species surveys (Ferland and Haig, 2002).

Remote analysis

Knowledge of habitat characteristics is a crucial component of wildlife management, yet the relationships between organisms and their habitats are not always well-understood. Prior to this study, Nicholls and Baldassarre (1990a) compared shoreline features with the presence or absence of wintering plovers and found that plover sites were characterized by greater percent mudflats, greater beach width, lower percent beach, and number of small inlets than sites where plovers were not recorded. Their study assumed that all sites with plovers were equal in habitat suitability and only explained 22 % of the total habitat variability for the Gulf of Mexico Coast. My study confirms the predominance of inter-tidal flats at plover sites and extends the analysis to incorporate abundance data. Results from the landscape analysis demonstrate that Piping Plovers winter at specific sites and characteristics of those habitats are not unique to those localities. Rather, certain landscape and anthropogenic features influence the distribution and abundance of plovers over the entire U.S. Gulf of Mexico coast. Specifically, shoreline features (i.e. inter-tidal area, inter-tidal and beach area, mainland category) and urbanization (i.e. urban area and roads) explain a significant proportion of variation in their abundance. The predictive model explains more variability in abundance and enables comparison of habitat composition across Gulf Coast wintering sites.

Wintering Piping Plovers are like many other shorebirds in that they inhabit inter-tidal zones with productive prey bases. Shorebird abundance is often related to the distribution of their prey, which in turn is related to the condition of sediments and shore profile (Goss-Custard et al., 1991; Yates et al. 1993). Fluctuations in invertebrate populations may result in significant mortality for large numbers of birds (Atkinson et al. 2000). Therefore, inter-tidal habitats are important for wintering plovers (Haig and Oring, 1985; Johnson and Baldassarre, 1988; Nicholls and Baldassarre, 1990b; Drake et al., 2001). My study extends this argument and demonstrates a functional relationship between shorebird abundance and the quantity of habitat. The inclusion of additional study sites would reduce the impact of extremely small or large inter-tidal areas and ultimately, enhance the strength of this statement. Because tidal areas (e.g. sand, mud, clay, or some mixture) vary across the Gulf of Mexico, innovative GIS technology (e.g. LIDAR inter-tidal elevation models) may enable greater flexibility and permit a more detailed remote analysis of how plover abundance is related to distinct inter-tidal zones.

International censuses located 73 % of wintering plovers on barrier islands (Ferland and

Haig, 2002). My study confirms those findings and demonstrates a relationship between plovers and landform; Piping Plovers winter on peninsulas and islands in higher abundances than on the mainland. Nicholls and Baldassarre (1990b) noted that "complex systems with several habitat types (i.e. roosting and feeding) in relatively close juxtaposition" are characteristic of winter plover habitat. The bayside of barrier islands provide adequate forage on tidal flats; whereas the Gulf side consists of sandy beaches for roosting.

Previous studies (Johnson and Baldassarre, 1988; Nicholls and Baldassarre, 1990b; Drake et al., 2001) investigated the relationship between plovers and several habitat characteristics (e.g. tidal flats, beaches, inlets), but neglected urbanization as influential to plover abundance and distribution. My study demonstrates that urban areas and roads appear to influence Piping Plover winter abundance; as the length of roads or amount of urban area increased, the number of plovers decreased. Urban areas and roads indicate the presence of humans and domesticated animals, known disturbances to Piping Plovers (Burger, 1991; Burger, 1994). Human disturbance appears to limit local Piping Plover abundance and vehicle use displaces plovers from preferential habitat (Zonick and Ryan 1995). Disturbance reduces time spent foraging (Burger 1991), increases energy expenditure (Zonick and Ryan 1995), and may ultimately reduce survivorship. Several factors associated with urban development threaten wintering habitat quality: recreational activities, inlet and shoreline stabilization, dredging of inlets, beach maintenance, and pollution (USFWS, 2001). Future urbanization poses a challenge for wintering plovers particularly in the states of Florida (3rd), Texas (4th), and Georgia (6th) with the fastest growing human populations (U.S. Census Bureau, 2003).

V. MANAGEMENT IMPLICATIONS AND RECOMMENDATIONS

Monitoring Wintering Sites

Regular visits to plover winter sites provide important information on plover abundance and habitat use that can be used to track population trends and identify site specific threats. This study identified 49 sites that define the winter distribution range of Piping Plovers in the U.S. Gulf and form the set of locations around which a winter monitoring program should be developed. Seasonal monitoring (e.g. four times between November and February) of all sites or a carefully selected subset, would serve multiple purposes. Such an effort would allow: comparisons of current and historic plover numbers, assessment of anthropogenic or geophysical changes to the sites, and evaluation of recreational activities and/or beach management policy. Synthesis of this information would be valuable at both local and regional scales to highlight unusual trends, facilitate conversation among managers across sites, and focus recovery efforts at vulnerable sites.

My study identified several sites where plovers warrant immediate attention. Piping Plovers winter on Honeymoon Island, FL, Caladesi Island, FL, and Mustang Island, TX in high abundances (30 individuals or greater). Recreational activity is intense at these locations. At all sites foot traffic is exceptionally high; at Mustang Island, high vehicular densities limit plover access to roosting locations. Management actions are needed to reduce disturbance to roosting and foraging plovers. Finally, several sites in the

Louisiana barrier islands support high abundances (≥30 individuals) of plovers. After severe hurricanes, some of the locations disappear entirely. For example, after Hurricane Ivan in 2004, the majority of the Chandeleur Islands, a traditional wintering location, were submerged. Individuals may seek refuge elsewhere, but where and in what abundances remains undetermined.

Protection of wintering sites

Coastal shorelines provide winter habitat for shorebirds and significant recreational opportunities for humans. Therefore, rates of coastal urbanization and outdoor recreation pose conflicts with shorebird survival needs. Evidence of human recreational activity (i.e. footprints, car and ORV tracks) was recorded at 80% of the sites visited during the Winter 2004 surveys. The following important recreation caused threats were identified: damage to roosting and foraging areas from foot traffic and vehicle access, frequent disturbance of foraging and roosting birds, and potential reduction of prey as a result of beach grooming activities. Disturbance to non-breeding organisms may have detrimental effects (Skagen et al. 1991); impediments to foraging or roosting increase energy expenditure (Burger, 1991; Zonick and Ryan, 1995). To reduce disturbance to wintering plovers, multiple methods to limit interactions may be explored. Lafferty (2001) parameterizes a model with the closure of ~15 % of Critical Habitat for wintering Western Snowy Plovers (*Charadrius alexandrius nivosus*); the plan would greatly reduce disturbance, but success is constrained by compliance of beach-goers. Amendments to this proposal could limit temporal or spatial access within an area. Micro-sites (for roosting or feeding) could be completely restricted, or access limited during tide cycles (beach access during low tide only). For example, Marco Island, FL restricts access to the inter-tidal area; plovers are able to forage relatively undisturbed on the resort island. In contrast, plovers in San Luis Pass, TX must contend with fishermen, pets, and their vehicles on both foraging and roosting habitat. Vehicle, leash, and beach access laws vary across the Gulf Coast; some locations are inaccessible to the public, yet others are resort destinations. A careful review of recreational policy and beach management for the entire U.S. Gulf of Mexico coastline should be a priority for Piping Plover and coastal ecosystem management efforts.

Increasing accuracy of the International Piping Plover census

The International Piping Plover Census is extensive in scope and occurs every five years. In 1991, 1996, and 2001, the winter censuses located 63, 42, and 40% of the estimated number of continental breeding birds, respectively (Haig and Plissner 1993; Plissner and Haig 2000, Ferland and Haig 2002). For organisms with a patchy distribution, like the Piping Plover, stratified sampling may be a preferable technique for estimating population size. Stratified sampling requires knowledge of the identity and location of preferred habitat. Results of this study would facilitate the effort because remote analysis could be performed for difficult or expensive to access locations. The model developed for this study would generate abundance estimates to help identify sites to survey based on time and cost. Second, > 1000 volunteers participate in the censuses; locations with few plovers may have many volunteers and vice versa. Stratified sampling will more appropriately distribute volunteer effort to represent the probability of encountering plovers. Finally, well-executed stratified sampling generates accurate measures with minimum variance. Therefore, a more accurate count of plovers would be generated with less effort.

Potential importance of Mexico's Gulf Coast for wintering plovers

The percentage of breeding individuals that have not been accounted for on the wintering grounds suggests that additional important unidentified habitat exists within or outside the U.S. The eastern Mexican coastline is highly inter-tidal, not urbanized, and strewn with barrier islands. This study indicates Mexico potentially hosts a substantial winter population. Mabee et al. (2001) located 739 Piping plovers (12% breeding population) in the Laguna Madre region of Texas and Mexico and noted "more thorough surveys of the Laguna Madre region are needed. They should cover mainland and barrier island habitats, and other coastal systems to the south (e.g. lagunas in Veracruz, MX).

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Table 1. Thirty-one U.S. Gulf of Mexico sites included in a remote analysis of Piping Plover winter habitat.

State	County	Site	Description
AL	Mobile	Dauphin Island Complex	urban; multiple beach and tidal barrier islands; Mississippi Sound; access varies across islands
FL	Bay	Bay Point Marriot	urban; tidal area and beach; St. Andrew Bay; foot access
FL	Collier	Big Marco Pass Shoal	urban; human-made island; Gulf of Mexico; tourist recreation; high access except for area closed for wildlife
FL	Escambia,Santa Rosa	Navarre Beach	urban and state park; on Santa Rosa Island; Gulf of Mexico; foot and boat access
FL	Franklin	Lanark Reef	tidal shoal; Gulf of Mexico; boat access
FL	Gulf	Cape San Blas	tidal area on St. Joseph Peninsula; St. Joseph Bay; foot access
FL	Pinellas	Honeymoon Island	state recreation area; barrier island; Gulf of Mexico and St. Joseph Sound; high access except for area closed for wildlife
FL	Pinellas	Shell Key	tidal shoal; close proximity to barrier islands; Gulf of Mexico; boat access
FL	Pinellas	Three Rooker Bar	tidal shoal; close proximity to barrier islands; Gulf of Mexico; boat access
FL	Pinellas	Caladesi Island	state recreation area; barrier island; Gulf of Mexico and St. Joseph Sound; high access except for area closed for wildlife
LA	Cameron	Cameron	urban; marsh, minimal beach; Calcasieu Lake and Gulf of Mexico; foot access
LA	Cameron	Holly Beach	urban; marsh, beach; Calcasieu Lake and Gulf of Mexico; foot access
LA	Jefferson	Barataria Pass (Grande Pass)	tidal area between barrier islands; Gulf of Mexico; boat access

LA	Jefferson	Caminada Pass (Southwest Pass)	west Mississippi delta; Mississippi River and Gulf of Mexico; boat access
LA	Plaquemines	Breton Island (Isle au Breton)	National Wildlife Refuge; marsh and tidal barrier island; Gulf of Mexico; limited access
LA	Plaquemines, St. Bernard	Chandeleur Islands	National Wildlife Refuge; marsh and tidal barrier islands; Gulf of Mexico; limited access
LA	St. Mary, Terrebone	Point Au Fer	marsh and tidal barrier island; Atchafalaya Bay, Fourleague Bay, and Gulf of Mexico; boat access
LA	Terrebone	Timbalier Island	barrier island; Gulf of Mexico; boat access
LA	Terrebone	Trinity Island (Central Isles Dernieres)	barrier island; Gulf of Mexico; boat access
TX	Aransas	San Jose Island	private; barrier island with extensive tidal area; Aransas Bay and Gulf of Mexico; charter boat access
TX	Aransas,Nueces	Aransas Pass/Port Aransas	tidal area dotted by series of islands in Redfish Bay and Aransas Bay; boat and limited foot access
TX	Brazoria	Follets Island	urban; island in close proximity to tidal area; Christmas Bay and Gulf of Mexico; foot access
TX	Calhoun	Matagorda Island, Aransas NWR	barrier island within Aransas National Wildlife Refuge; extensive marsh and tidal area on backbay; Espiritu Santo Bay; access via charter boat
TX	Cameron	Laguna Atascosa	National Wildlife Refuge; extensive tidal area and series of islands and sand dunes; Laguna Madre; limited access
TX	Galveston	Bolivar Flats	TNC land; tidal area bordered by jetty, beach and marsh area; foot access

TX	Kenedy, Kleberg, Willacy	South Padre Island	National Park; barrier island with tidal flats; Laguna Madre and Gulf of Mexico; foot access on Gulf side; limited access
TX	Kleberg, Nueces	North Padre Island	urban and National Park; barrier island with tidal flats; Laguna Madre and Gulf of Mexico; foot access on Gulf side; limited access on bayside
TX	Matagorda	Matagorda Peninsula	barrier island with extensive tidal area; Matagorda Bay and Gulf of Mexico; foot and boat access
TX	Nueces	Flour Bluff, Corpus Christi	urban; tidal area between Mustang and Padre Islands; Corpus Christi Bay and Laguna Madre; boat access
TX	Nueces	Mustang Island	barrier island with extensive bayside mudflats; Corpus Christi Bay; high beach activity on GC side: driving and recreation; backbay relatively inaccessible
TX	Nueces	Tule Lake	urban; tidal lagoon; near Nueces Bay; boat and foot access

Table 2. Geo-referenced descriptions of 31 Gulf of Mexico sites included in a remote analysis of Piping Plover winter habitat. (IPPC= International Piping Plover Census; JS= Stucker et al. 2003; LANHP= Louisiana Natural Heritage Program; PS= Personal Survey)

State	Site Name	Location		Source
TX	Corpus Christi (Flour Bluff)	N 27 38 0	W 97 17 0	IPPC
	Laguna Atascosa	N 26 25 0	W 97 21 0	IPPS
	Mustang Island	N 27 46 0	W 97 08 0	IPPC
	Aransas NWR (Matagorda Island)	N 28 19 14	W 96 26 44	PS
	Aransas Pass/Port Aransas	N 27 92 46	W 97 06 40	PS
	Bolivar Flats	N 29 22 10	W 94 43 90	PS
	Matagorda Peninsula	Matagorda Peninsula, bayside, Colorado River, S of mouth	x	IPPC
	N. Padre Island	N 27 24 92	W 97 18 08	PS
	S. Padre Island	Port Mansfield Pass	x	IPPC
	San Jose Island	N pass area, bay	x	IPPC
	Follets Island	N 28 57 00	W 95 17 24	IPPC
	Tule Lake	N 27 51 00	W 97 32 00	IPPC
LA	Breton Island	lower 1/2, S portion of island	x	LANHP
	Chandeleur Islands (Chandeleur Light)	Chandeleur Light	x	LANHP
	Trinity Island (Central Isles Dernieres)	Central Isles Deniers	x	LANHP
	Timbalier Island	E end of the island	x	LANHP
	Cameron	follow E jetty from town, to end, walk E to beach	x	LANHP
	Point Au Fer NE	islands E of navigation channel	x	LANHP
	Barataria Pass	overwash areas	x	LANHP
	Caminada Pass	cut b/w Elmer's and Fourchon	x	LANHP
	Holly Beach	E Holly Beach	x	LANHP
AL	Pelican Island	SE end	x	JS
FL	Bay Point Marriot	N 30 08 14	W 85 43 32	IPPC
	Big Marco Pass	N 25 57 08	W 81 45 07	IPPC
	Lanark Reef	N 29 52 34	W 84 34 27	IPPC
	Cape San Blas	N 29 40 43	W 85 19 48	IPPC
	Honeymoon Island	N 28 04 58	W 82 50 20	IPPC
	Shell Key	N 27 39 47	W 82 44 25	IPPC
	Three Rooker Bar	N 28 07 17	W 82 50 29	IPPC
	Navarre Beach	N 30 23 18	W 86 50 45	IPPC
	Caladesi Island	N 28 01 50	W 82 49 20	IPPC

Table 3. Current wintering sites with reported Piping Plover abundance of ≥30 individuals.
(AB= American Birds; BFL= Birds of Florida; CBC= Christmas Bird Count; FN= Field Notes; IPPC= International Piping Plover Census; JS= Stucker et al. 2003; LANHP= Louisiana Natural Heritage Program)

State	County	Source	Site	Description
AL	Mobile	CBC, IPPC, JS	Dauphin Island Complex	urban; multiple beach and tidal barrier islands; Mississippi Sound; access varies across islands
FL	Collier	IPPC	Big Marco Pass Shoal	urban; human-made island; Gulf of Mexico; tourist recreation; high access except for area closed for wildlife
FL	Pinellas	AB, IPPC	Honeymoon Island	state recreation area; barrier island; Gulf of Mexico and St. Joseph Sound; high access except for area closed for wildlife
FL	Franklin	AB,FN,IPPC	Lanark Reef	tidal shoal; Gulf of Mexico; boat access
FL	Gulf	CBC	Port St. Joe	urban; limited tidal area and barrier islands in close proximity; St. Joseph Bay; moderate access
FL	Pinellas	IPPC	Shell Key	tidal shoal; close proximity to barrier islands; Gulf of Mexico; boat access
FL	Pinellas	IPPC	Three Rooker Bar	tidal shoal; close proximity to barrier islands; Gulf of Mexico; boat access
LA	Jefferson	IPPC, LANHP	Barataria Pass (Grande Pass)	tidal area between barrier islands; Gulf of Mexico; boat access
LA	Plaquemines	IPPC, LANHP	Breton Island (Isle au Breton)	National Wildlife Refuge; marsh and tidal barrier island; Gulf of Mexico; limited access
LA	Plaquemines, St. Bernard	IPPC, LANHP	Chandeleur Islands	National Wildlife Refuge; marsh and tidal barrier islands; Gulf of Mexico; limited access
LA	Terrebone	IPPC	Last Island (Isle Dernier)	barrier island; Gulf of Mexico; boat access
LA	Terrebone	IPPC, LANHP	Timbalier Island	barrier island; Gulf of Mexico; boat access
LA	Terrebone	IPPC	Trinity Island (Central Isles Dernieres)	barrier island; Gulf of Mexico; boat access
TX	Aransas,Nueces	CBC	Aransas Pass/Port Aransas	tidal area dotted by series of islands in Redfish Bay and Aransas Bay; boat and limited foot access

TX	Galveston	CBC, IPPC, JS	Bolivar Flats	TNC land; tidal area bordered by jetty, beach and marsh area; foot access
TX	Brazoria	CBC	Cedar Lakes, San Bernard NWR	National Wildlife Refuge; marsh and lagoon system; Gulf of Mexico and Cedar Lakes; foot and boat access
TX	Nueces	CBC, IPPC	Flour Bluff, Corpus Christi	urban; tidal area between Mustang and Padre Islands; Corpus Christi Bay and Laguna Madre; boat access
TX	Cameron	CBC, IPPC	Laguna Atascosa	National Wildlife Refuge; extensive tidal area and series of islands and sand dunes; Laguna Madre; limited access
TX	Matagorda	CBC	Mad Island Marsh	Wildlife Management Area; marsh and tidal reef system; Matagorda Bay; boat access
TX	Calhoun	IPPC	Matagorda Island, Aransas NWR	barrier island within Aransas National Wildlife Refuge; extensive marsh and tidal area on backbay; Espiritu Santo Bay; access via charter boat
TX	Matagorda	IPPC	Matagorda Peninsula	barrier island with extensive tidal area; Matagorda Bay and Gulf of Mexico; foot and boat access
TX	Nueces	AB, FN, IPPC	Mustang Island	barrier island with extensive bayside mudflats; Corpus Christi Bay; high beach activity on GC side: driving and recreation; backbay relatively inaccessible
TX	Kleberg, Nueces	IPPC	North Padre Island	urban and National Park; barrier island with tidal flats; Laguna Madre and Gulf of Mexico; foot access on Gulf side; limited access on bayside
TX	Aransas	IPPC	San Jose Island	private; barrier island with extensive tidal area; Aransas Bay and Gulf of Mexico; charter boat access
TX	Kenedy, Kleberg, Willacy	IPPC	South Padre Island	National Park; barrier island with tidal flats; Laguna Madre and Gulf of Mexico; foot access on Gulf side; limited access

Table 4. Current wintering sites with reported Piping Plover abundance of 15-29 individuals.
(AB= American Birds; BFL= Birds of Florida; CBC= Christmas Bird Count; FN= Field Notes; IPPC= International Piping Plover Census; JS= Stucker et al. 2003; LANHP= Louisiana Natural Heritage Program)

State	**County**	**Source**	**Site**	**Description**
FL	Pinellas	IPPC	Caladesi Island	state recreation area; barrier island; Gulf of Mexico and St. Joseph Sound; high access except for area closed for wildlife
FL	Pinellas	IPPC	Ft DeSoto/Pass-a-Grille	county park; on Mullet Key--barrier island; Gulf of Mexico; high access
LA	Cameron	CBC	Sabine NWR	state park; marsh and lagoon system; Gulf of Mexico; boat access
LA	Jefferson	IPPC, LANHP	Caminada Pass (Southwest Pass)	west Mississippi delta; Mississippi River and Gulf of Mexico; boat access
LA	Lafourche	IPPC	Belle Pass	marsh and tidal delta; Timbalier Bay and Gulf of Mexico; boat access
LA	St. Mary, Terrebone	IPPC, LANHP	Point Au Fer	marsh and tidal barrier island; Atchafalaya Bay, Fourleague Bay, and Gulf of Mexico; boat access
TX	Brazoria	CBC	Freeport	urban; close proximity to tidal area and beach; Gulf of Mexico; foot and boat access
TX	Jefferson	CBC	Sea Rim State Park	state park; marsh and lagoon system; Gulf of Mexico; boat access

Table 5. Current wintering sites with reported Piping Plover abundance of 1-14 individuals.
(AB= American Birds; BFL= Birds of Florida; CBC= Christmas Bird Count; FN= Field Notes; IPPC= International Piping Plover Census; JS= Stucker 2003; LANHP= Louisiana Natural Heritage Program)

State	County	Source	Site	Description
AL	Baldwin	CBC	Fort Morgan	urban; peninsular point; Bon Secour Bay and Gulf of Mexico; foot and boat access
AL	Baldwin	CBC	Gulf Shores	urban; peninsula with beach area; Gulf of Mexico; foot access
FL	Bay	IPPC	Bay Point Marriot	urban; tidal area and beach; St. Andrew Bay; foot access
FL	Bay	BFL, IPPC	Crooked Island	Air Force; barrier island; St. Andrew Sound and Gulf of Mexico; restricted access
FL	Escambia	CBC	Perdido Bay	urban; marsh and beach; Perdido Bay and Gulf of Mexico; boat access
FL	Escambia	BFL, IPPC	Big Sabine Point	tidal area on Santa Rosa Island; Santa Rosa Sound and Gulf of Mexico; foot and boat access
FL	Escambia,Santa Rosa	IPPC, JS	Navarre Beach	urban and state park; on Santa Rosa Island; Gulf of Mexico; foot and boat access
FL	Franklin	CBC, IPPC	St. Vincent NWR	National Wildlife Refuge; barrier island; Apalachicola Bay, St. Vincent Sound, and Gulf of Mexico; limited access
FL	Gulf	IPPC	Cape San Blas	tidal area on St. Joseph Peninsula; St. Joseph Bay; foot access
FL	Levy	CBC	Cedar Key	protected area; small barrier islands and tidal areas; Gulf of Mexico; limited access
FL	Pasco	CBC	Aripeka/Bayport	urban; tidal area and small islands in close proximity; foot and boat access
LA	Cameron	IPPC, JS	Cameron	urban; marsh, minimal beach; Calcasieu Lake and Gulf of Mexico; foot access
LA	Cameron	IPPC	Holly Beach	urban; marsh, beach; Calcasieu Lake and Gulf of Mexico; foot access
TX	Aransas	CBC	Rockport	urban; close proximity to tidal area and island; Aransas Bay; foot and boat access

TX	Brazoria	IPPC	Follets Island	urban; island in close proximity to tidal area; Christmas Bay and Gulf of Mexico; foot access
TX	Nueces	IPPC	Tule Lake	urban; tidal lagoon; near Nueces Bay; boat and foot access

Table 6. Results from simple linear regression. From the set of 11 parameters, the five parameters in bold were found to be significant predictors of Piping Plover abundance on the U.S. Gulf of Mexico coast.

REGION	**GULF COAST (GC) n=31**
PARAMETER	Adjusted R-squared, p-value, (df)
INTER-TIDAL AREA	**0.1611, 0.013 (30)**
URBAN AREA	**0.1748, 0.011 (30)**
PENINSULA	**0.2875, 0.001 (30)**
TOTAL AREA	**0.1675, 0.012 (30)**
ROADS	**0.0975, 0.049 (30)**
BEACH	-0.0159, 0.47 (30)
ACCESS POINTS	0.0783, 0.11 (21)
BOAT LAUNCHES	0.08481, 0.10 (21)
LAGOON	0.0453, 0.13 (30)
LAGOON PERIMETER	0.0317, 0.17 (30)
RIVER	-0.0258, 0.62 (30)

Figure 1. Thirty-one sites on the U.S. Gulf of Mexico coast included in the GIS analysis of Piping Plover winter habitat.

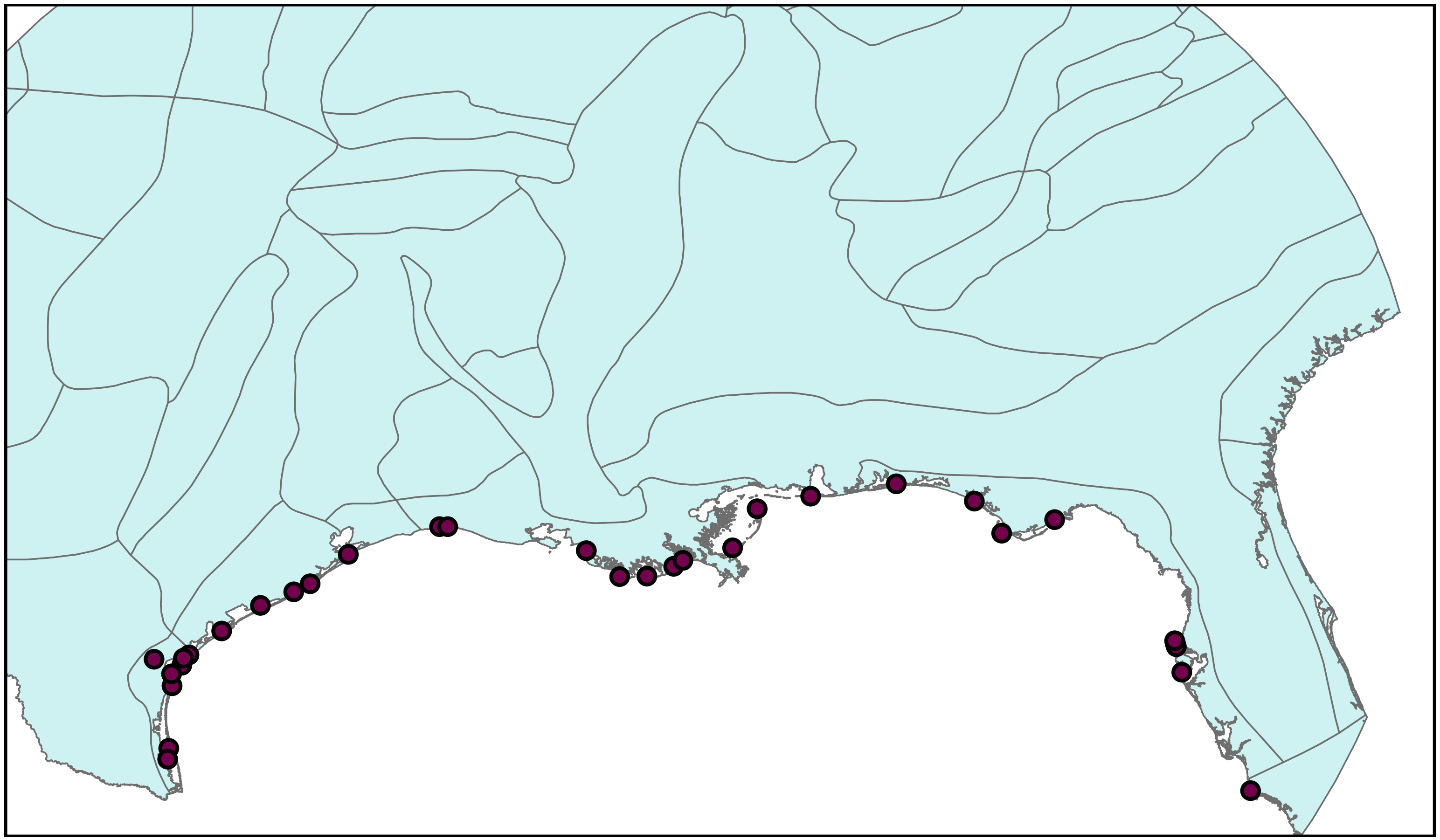

Figure 2. Digital Orthographic Quad (DOQ) of Matagorda Island, Aransas NWR, Texas. National Aerial Photography Program (NAPP).1997-2000. Digital Orthographic Quads. U.S. Geological Survey (coordinator). Reston, Virginia.

Figure 3. Image of Matagorda Island, Aransas NWR, Texas with geo-referenced PIPL location and 3 km buffer. National Aerial Photography Program (NAPP).1997-2000. Digital Orthographic Quads. U.S. Geological Survey (coordinator). Reston, Virginia.

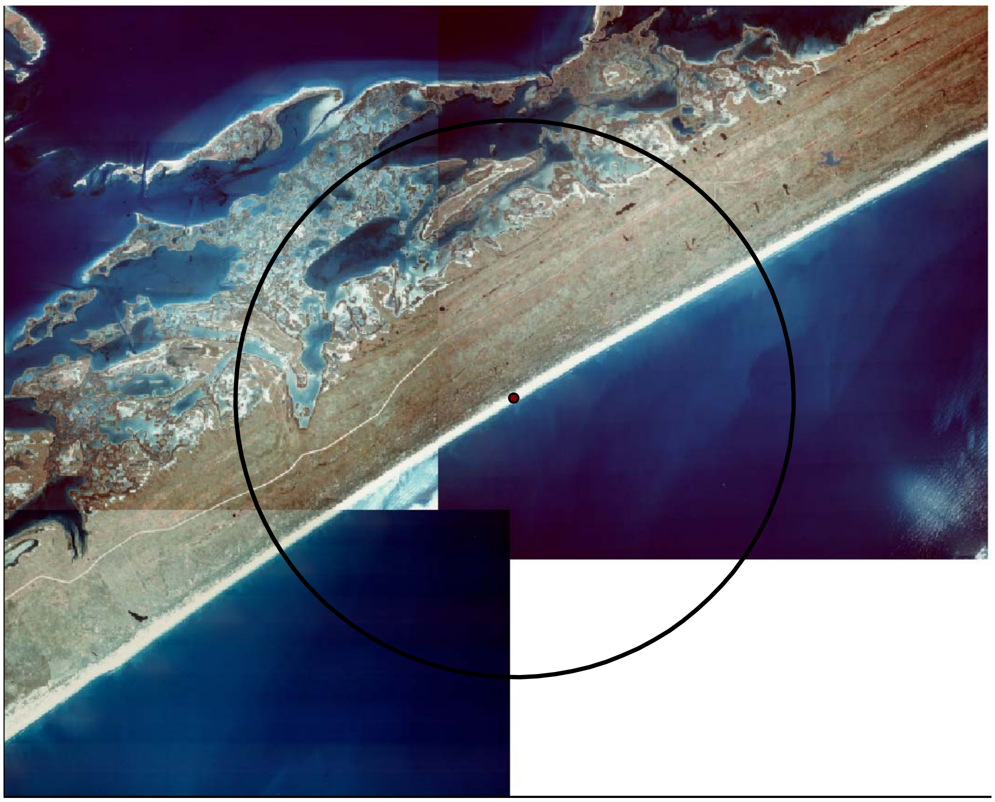

Figure 4. A digitized image of Matagorda Island, Aransas NWR, Texas showing basic habitat categories.

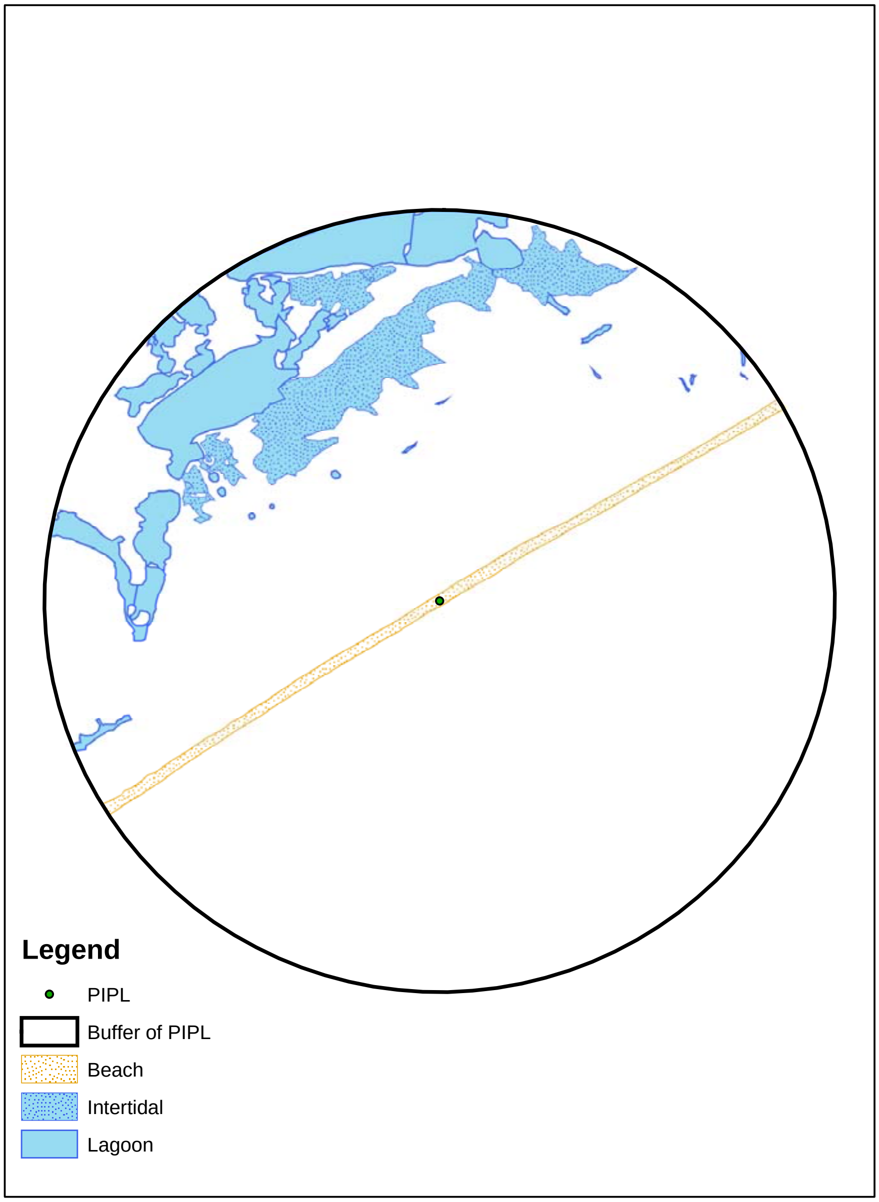

Figure 5. Digital Raster Graphic (DRG) of Matagorda Island, Aransas NWR, Texas. U.S. Geological Survey. 1995-2001. Digital Raster Graphics. Reston, Virginia.

Figure 6. Results from the Winter 2004 survey showing sites in Florida and Texas with non-zero counts of wintering Piping Plovers The figure displays the maximum count and standard deviation for locations. Survey locations are arranged geographically from southern Florida to southern Texas.

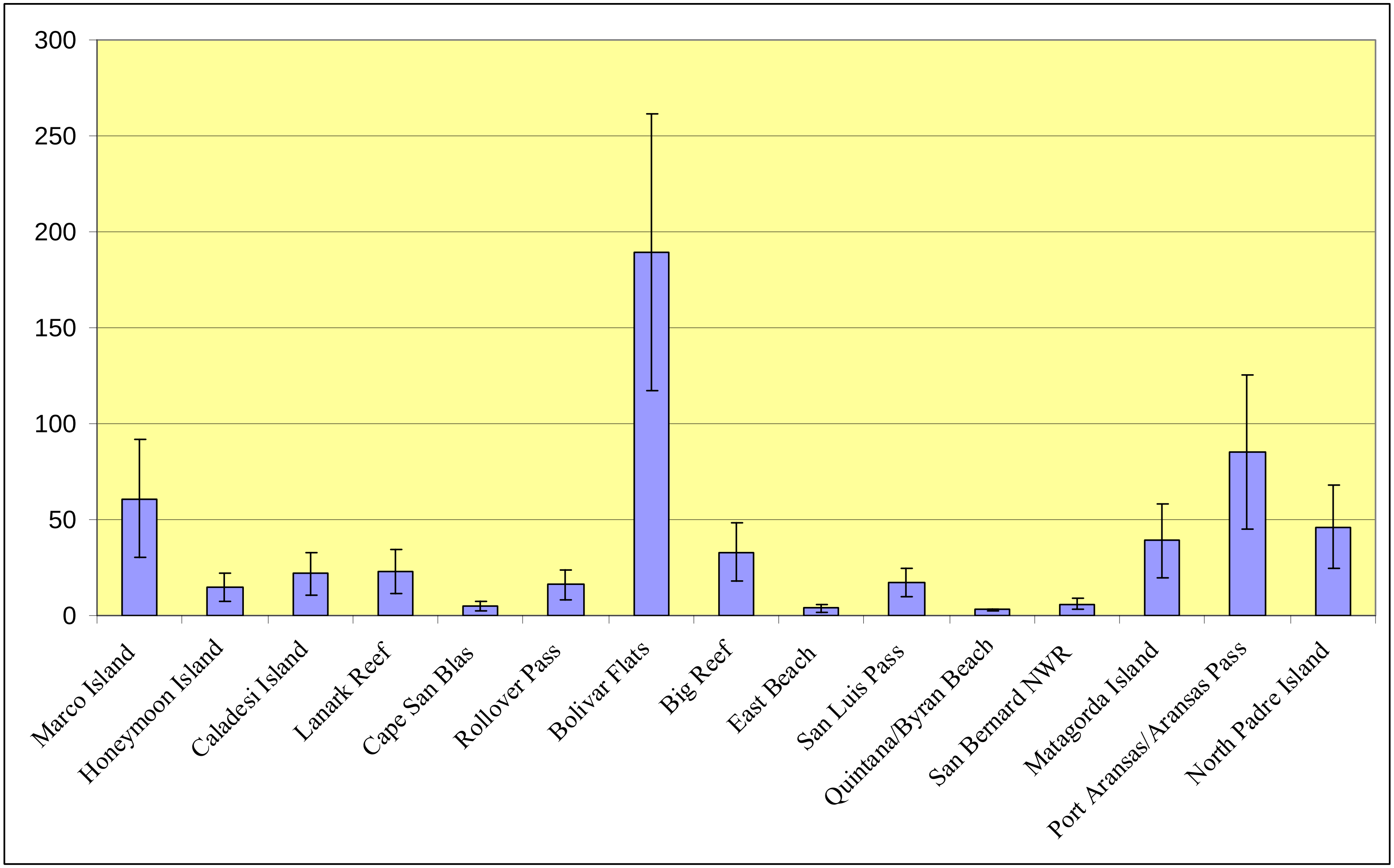

Figure 7. A significant predictor of Piping Plover abundance on the U.S. Gulf of Mexico coast: PIPL abundance is negatively correlated with urban area (km^2).

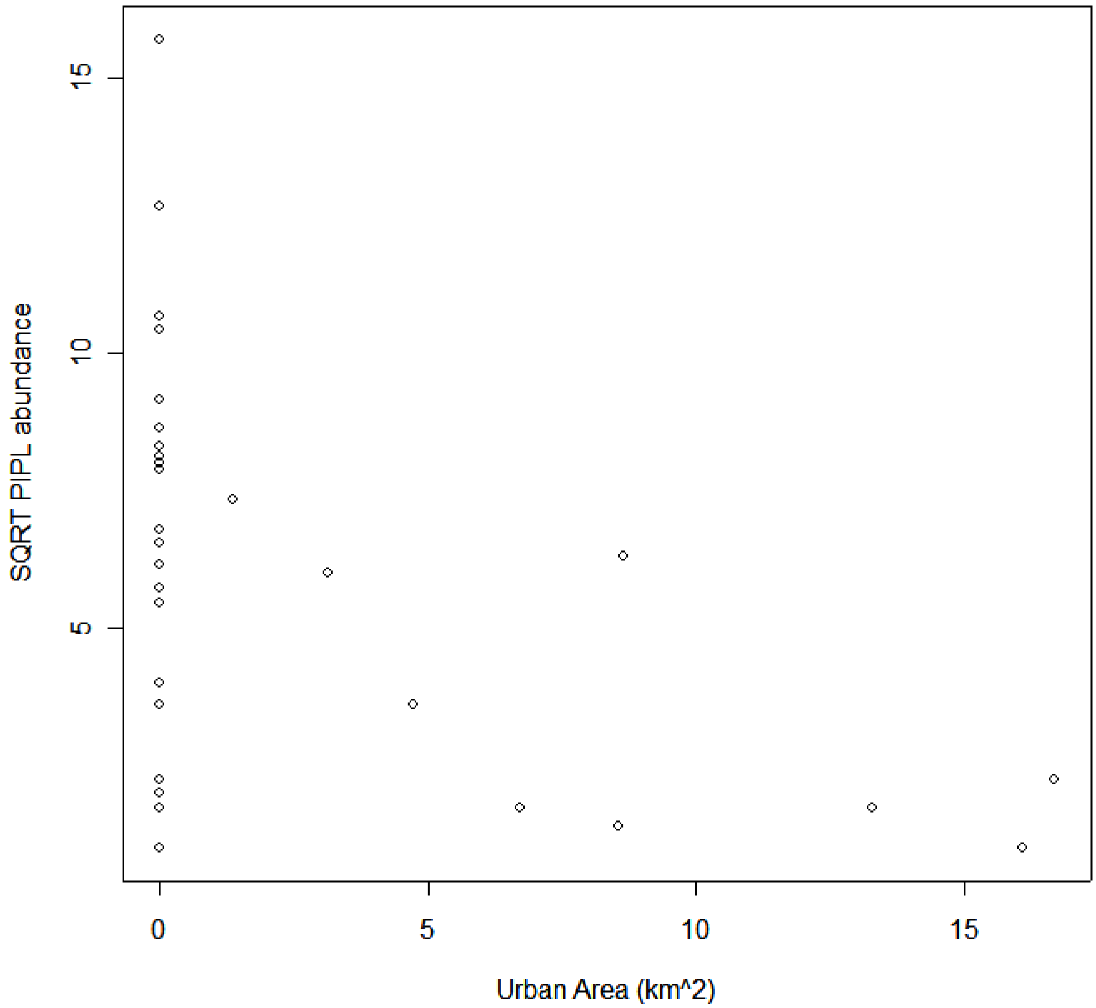

Figure 8. A significant predictor of Piping Plover abundance on the U.S. Gulf of Mexico coast: PIPL abundance is negatively correlated with road length (km).

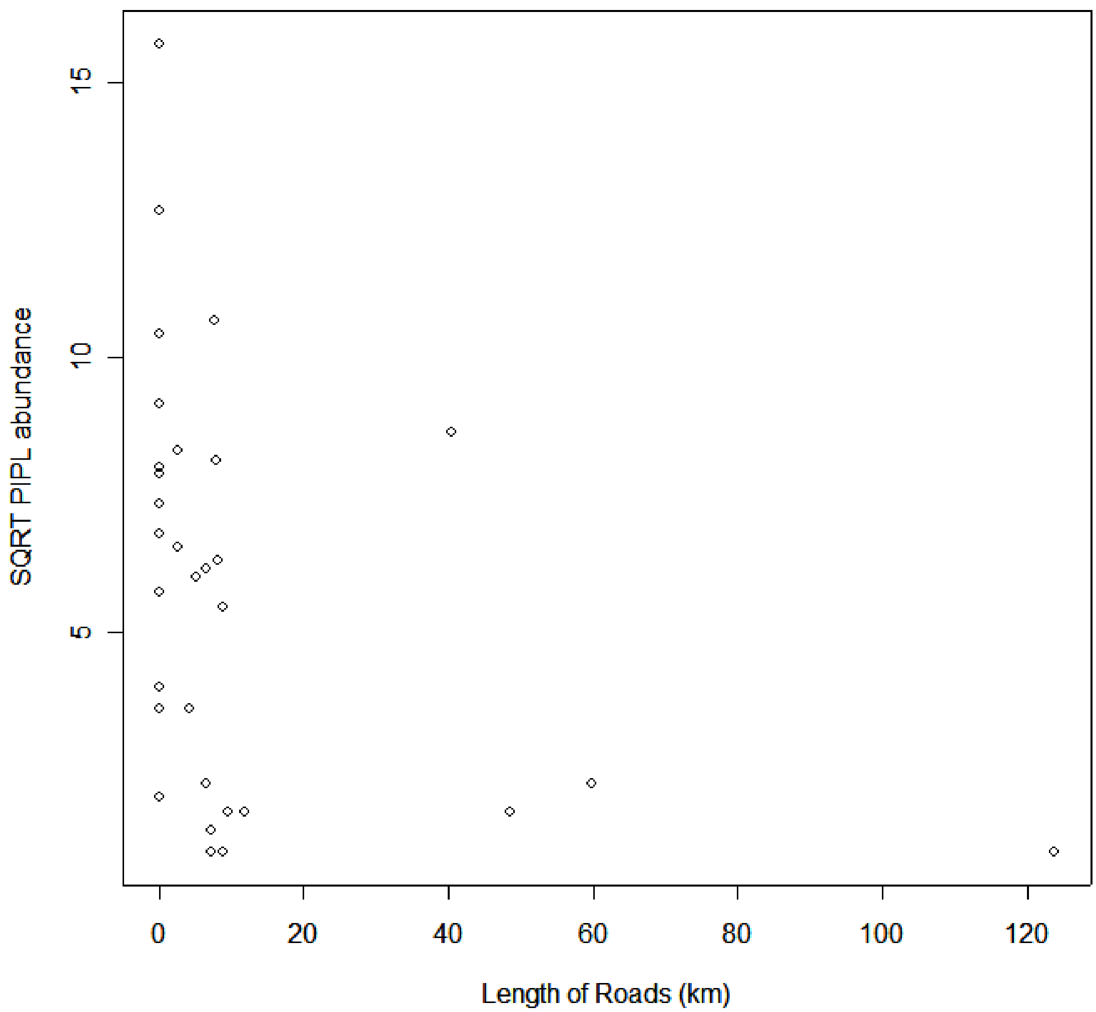

Figure 9. A significant predictor of Piping Plover abundance on the U.S. Gulf of Mexico coast: PIPL abundance is positively correlated with inter-tidal area (km^2).

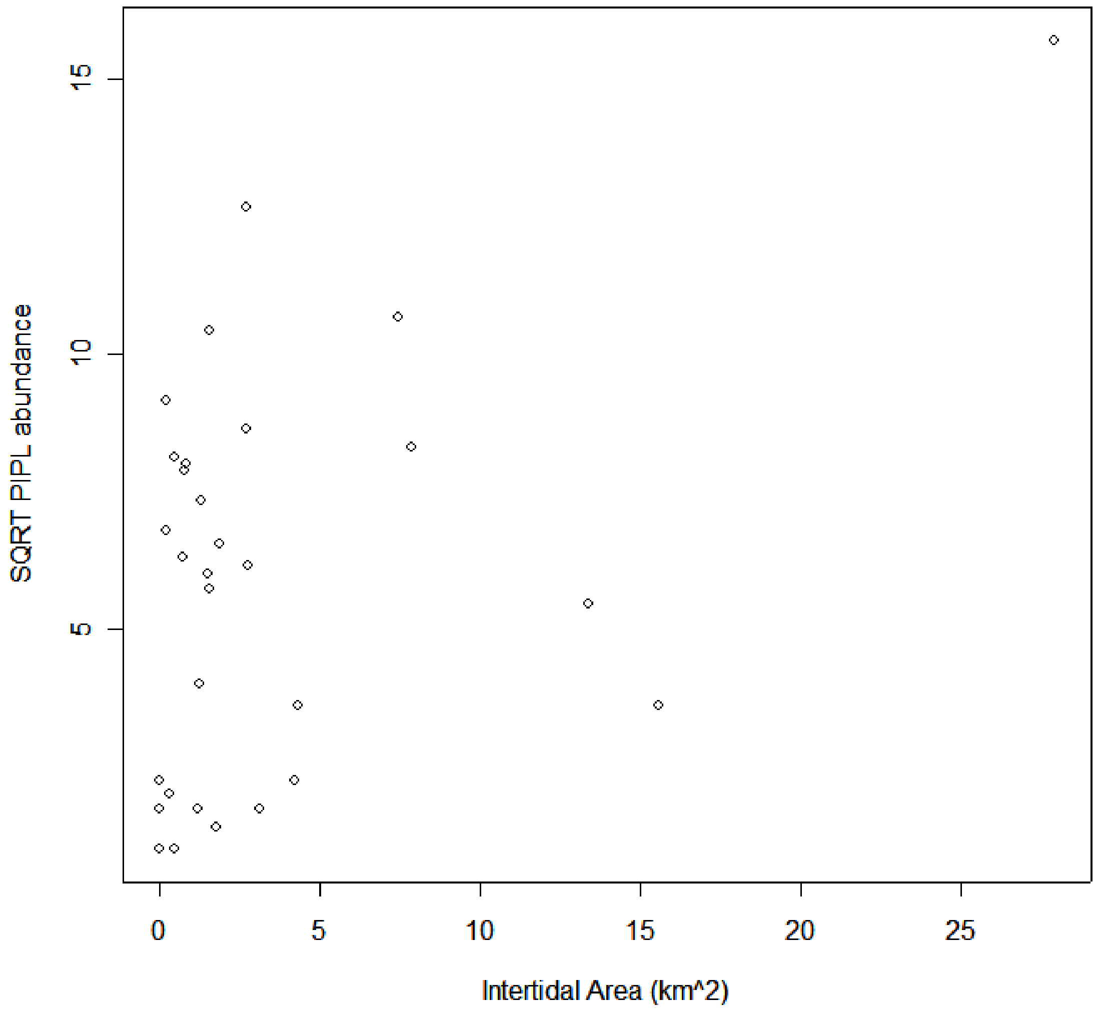

Figure 10. A significant predictor of Piping Plover abundance on the U.S.Gulf of Mexico coast: PIPL abundance is positively correlated with island/peninsula landforms.

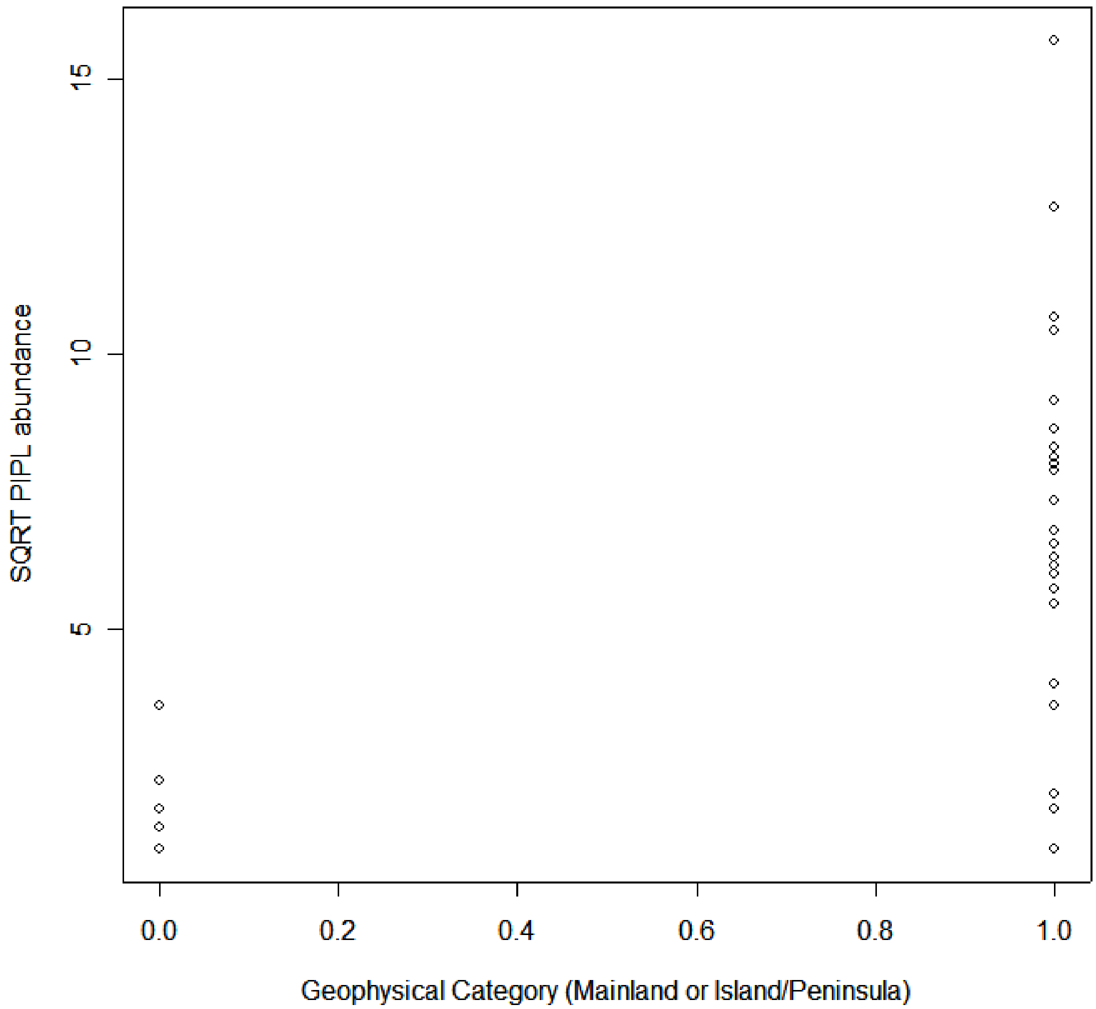

Figure 11. A significant predictor of Piping Plover abundance on the U.S. Gulf of Mexico coast: PIPL abundance is positively correlated with inter-tidal and beach area (km^2).