

**The Effects of Dredge Material on Piping Plovers and Snowy
Plovers Along the Southern Laguna Madre of Texas**

Final Report 1997-1999

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FINAL REPORT (1997-1999)

The Effects of Dredged Material on Piping Plovers and Snowy Plovers

RESPONSIBLE ORGANIZATION

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PROJECT OVERVIEW

Like most shorebirds, Piping Plovers (*Charadrius melodus*) spend the majority of their annual cycle away from breeding areas where they rely on limited coastal habitats. During the nonbreeding period, Piping Plovers occur primarily along the coastlines of the Gulf of Mexico and southern Atlantic Coast (Haig and Oring 1985, Nicholls and Baldassarre 1990). Because human populations are also concentrated along coastlines, loss of coastal habitats through development threatens many shorebird populations (Senner and Howe 1984) and has been directly attributed to the decline of Piping Plover populations (U.S. Fish and Wildlife Service 1985). Other human-related activities that may negatively affect shorebird coastal habitats include dredging operations (Haig and Plissner 1993). Thus, understanding nonbreeding ecology of Piping Plovers and their reliance on limited coastal habitats is important (Myers 1983, Haig and Plissner 1993).

We investigated the effects of dredged material placement areas (DMPAs) on the wintering ecology of the federally threatened Piping Plover (U.S. Fish and Wildlife Service 1985) and the Snowy Plover (*C. alexandrinus*). Currently, the Snowy Plover is not listed as threatened or endangered in Texas, however, the Pacific Coast population was recently listed as threatened (U.S. Fish and Wildlife Service 1993). Many of the factors contributing to the decline of the Pacific Coast population of Snowy Plovers

(i.e., human disturbance, increased nest predation, habitat destruction, see U.S. Fish and Wildlife Service 1993) also occur along the Texas Coast, where Snowy Plover distribution has been reduced and fragmented (Williams 1938, Page et al. 1995)

This report summarizes the findings from the 1998-1999 field season investigating Piping Plover habitat use, inter-annual site fidelity of Piping and Snowy Plovers, and winter surveys for captive-reared Piping Plovers. We include a Piping Plover population estimate for the southern Laguna Madre and present a more rigorous analysis of the 1997-1998 Piping Plover radio-telemetry data investigating seasonal habitat use, movements, and home range size. Additionally, we present an analysis comparing habitat components of Piping and Snowy Plover roost sites.

Interannual fidelity.

Between August 1997 and May 1998, we banded 50 Piping Plovers and 31 Snowy Plovers with unique color-band combinations. We placed radiotransmitters on 49 Piping Plovers and four Snowy Plovers, and tracked movements of radioed birds throughout the life of the radios (average = 58 days). Continued research during the 1998-1999 season will provide additional information of plover habitat use and estimates on return rates (site fidelity) of individual plovers.

The 1997-1998 season revealed strong patterns of intra-annual (within year) fidelity to habitats along the southern Laguna Madre by wintering plovers. Research during the 1998-1999 season emphasized inter-annual (between years) site fidelity to determine if, and to what degree, plovers return to the same wintering area used during the previous year. Knowledge of the extent of inter-annual site fidelity will provide a better understanding of plover winter ecology, which is essential for developing sound conservation and management plans.

The southern Laguna Madre wetland complex is a Gulf Coast stronghold for Piping and Snowy Plovers. During a single survey on 17 February 1998, we counted 499 Piping Plovers on South Padre Island. The current total population estimate for Piping Plovers is 5,500 individuals (Plissner and Haig in review). This means that at least 9% of the entire Piping Plover population uses habitats associated with the

southern Laguna Madre, which emphasizes the importance of understanding Piping Plover habitat use in this region

Movements, Home Range Size, Habitat Use and Survival.

Information on movements between habitat types and the proportion in which Piping Plovers use these habitats throughout the nonbreeding period is critical in order to identify habitats most important to wintering Piping Plovers. Moreover, baseline knowledge of winter mortality rates is essential to assess how loss of winter habitat might affect population levels (Ryan et al. 1993)

The coast of Texas is a major wintering area for Piping Plovers (i.e., contains 55% of birds found during winter censuses) (Nicholls and Baldassarre 1990, Haig and Plissner 1993) where birds spend up to 75% of their annual cycle (Drake et al. unpublished). Importantly, Texas coastlines are also where more than 4.5 million people reside along with nearly 70% of the state's total industrial based commerce (Moulton et al. 1997), further emphasizing threats due to potential loss of habitat through development.

Beyond continental distribution, little is known about winter habitat use, movements or survival. Thus, the objectives of this study were to determine seasonal variation in home range size, identify important habitat types used by wintering Piping Plovers, and assess winter survival of Piping Plovers. Because shorebird movements generally correspond with availability of habitats (Gerstenberg 1979, Myers 1984, Warnock and Takekawa 1996), movements should increase as habitat availability increases. We hypothesized that home range size would vary among seasons, with winter home range size being larger than fall and spring because seasonal low tides during winter increase habitat availability along the southern Laguna Madre. Lastly, given that annual survival of shorebirds is generally 70% - 95% (Evans and Pienkowski 1984), we hypothesized winter survival of Piping Plovers would be > 70%

Roosting Habitat of Piping and Snowy Plovers

Nonbreeding shorebirds allocate most of their time to foraging and roosting (Puttick 1979, Johnson and Baldassarre 1988, Morrier and McNeil 1991, Kalejta 1992, K

L. Drake 1999) Although wintering shorebirds spent a significant portion of their time roosting, most studies have focused primarily on their foraging ecology (e.g., Recher and Recher 1969, Baker and Baker 1973, Evans 1976, Goss-Custard 1969, 1980 Goss-Custard et al. 1977, Pienkowski 1983). Wintering Piping Plovers spend approximately 20% of the day roosting (Johnson and Baldassarre 1988, K. L. Drake 1999), while nonbreeding Snowy Plovers roost up to 40% of the day (K. L. Drake 1999).

Macrohabitat selection of roost sites is often determined by habitat availability during high tides (Heppleston 1971, Hartwick and Blaylock 1979, Kelly and Cogswell 1979, Swennen 1984). Wintering shorebirds typically move between roosting and foraging areas (Kelly and Cogswell 1979, Ruiz et al. 1989, Handel and Gill 1992) and movements can range from a few meters to several kilometers (Kelly and Cogswell 1979, Myers and Myers 1979, Myers 1984, Swennen 1984). Shorebirds often congregate at roosts in multispecific flocks (Kelly and Cogswell 1979, Ruiz et al. 1989, Handel and Gill 1992), that segregate into smaller monospecific groups (Ruiz et al. 1989, Fasola and Biddau 1997). The occurrence of large movements and/or congregating in flocks to roost has prompted speculation about the adaptive significance of roosting behavior and roost site selection (see Myers 1984 for review).

There appears to be considerable variation in microhabitat selection of roost sites including roosting in open habitats, or on the leeward side of a topographic feature, or roosting within vegetation (Hartwick and Blaylock 1979, Kelly and Cogswell 1979, Ruiz et al. 1989, Handel and Gill 1992). However, most descriptions of roost sites are anecdotal and lack quantification of physical characteristics that may influence roost site selection.

Although roosting is a major component of time allocation in wintering plovers, the physical characteristics of plover roost sites have remained unstudied. Thus, the objectives of this study were to 1) identify macrohabitats used by roosting Piping and Snowy Plovers, 2) identify and quantify microhabitat characteristics at individual plover roost locations, 3) make interspecific comparisons of microhabitat characteristics between Piping and Snowy Plover roosts. We hypothesized that roost sites would possess unique microhabitat characteristics relative to random sites. Because Piping and Snowy Plovers

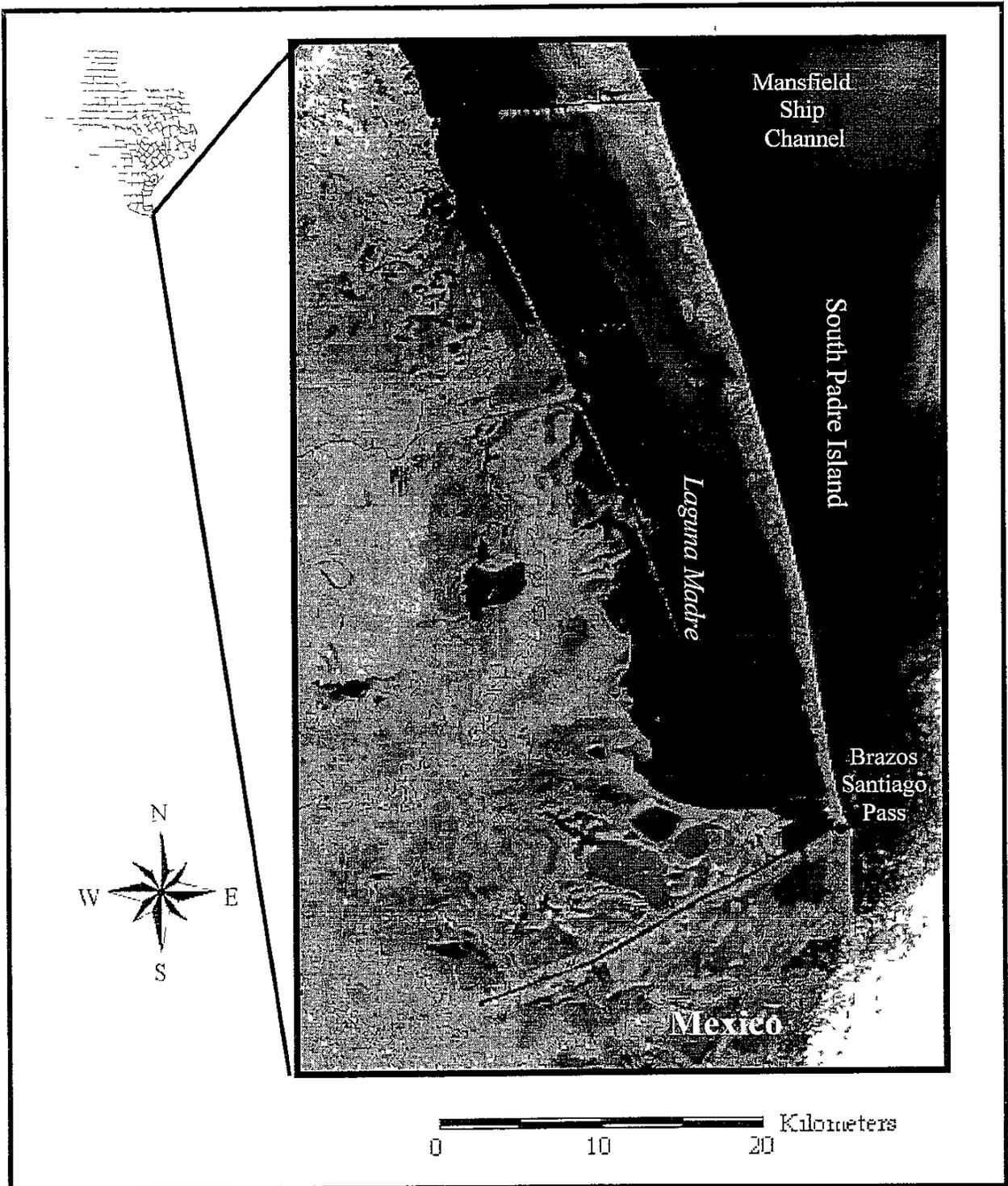
are closely related (same genus) and are of similar size and plumage we predicted they would select for the same macrohabitat types and microhabitat characteristics at roost sites

STUDY AREA

The primary study area was South Padre Island (26° 10' N, 97° 10' W), a 55 km long barrier island along the coast of south Texas, extending from the Mansfield Ship Channel south to Brazos Santiago Pass (Fig 1). South Padre Island is bordered to the west by the hypersaline Laguna Madre and to the east by the Gulf of Mexico. The island ranges from 450 m to 6 km in width, depending on tidal fluctuations, and is characterized by four main habitats including 1) beach (intertidal area to seaward base of primary dunes), 2) dunes (primary and secondary dunes with associated coastal prairies), 3) washover passes (areas where storm surges have cut transverse features across other habitat types), and 4) tidal flats (areas regularly inundated by water from the Laguna Madre following high tides, heavy rains, or seiches). Tidal flats consist of lower sandflats (areas generally inundated by the Laguna Madre and exposed only during low tides or seiches), algal flats (dense Blue-green algae [*Lyngbya* spp.] growing on the surface of sandflats), and upper sandflats (inundated only during extreme high tides and seiches). Tidal flats and washover passes are relatively void of vegetation. Judd et al. (1977) provide additional details on South Padre Island habitats and topography. The southernmost 9 km of South Padre Island are extensively developed and tidal flats \leq 10 km north of the developed region of the island receive regular disturbance in the form of automobile traffic. Areas to the north of this zone receive relatively little disturbance.

The natural depth of the southern Laguna Madre averages < 1 m (Breuer 1962). Because of the shallow nature of lagoonal habitats, bayshore tides on South Padre Island are greatly influenced by seiches and are not synchronized with beach tides (Breuer 1962). In addition, limited, narrow channels extending into the Gulf of Mexico (Port Mansfield Ship Channel, 30.5 m in width, and Brazos Santiago Pass, 91.4 m in width) regulate the amount of water entering and exiting the Laguna Madre at any given time,

Figure 1 Southern Laguna Madre of Texas



causing a delay in lunar tide influence relative to beach tides (Breuer 1962) Seiches often inundate tidal flats in one area while exposing those of another, depending upon direction, strength, and duration of wind Salinity levels within the southern Laguna Madre are highest during late summer and early fall due to high rates of summer evaporation accompanied by little precipitation (Breuer 1962, Hedgepeth 1967, Withers 1994) Additionally, prevailing southeast winds during fall create a south-to-north salinity gradient, with salinity being lowest nearer Brazos Santiago Pass, where seawater enters from the Gulf of Mexico (see Breuer 1962)

To permit ship traffic, channels extending the full length of the Laguna Madre (Gulf Intracoastal Water Way) and perpendicular channels extending into the Gulf of Mexico (Mansfield Ship Channel and Brazos Santiago Pass) are dredged on a regular basis Currently, some of the dredged materials are disposed of by placing them in man-made impoundments built on mainland tidal flats and the rest are placed in open-bay unconfined sites The study area was selected due to accessibility, proximity to dredged material placement areas (DMPAs), and traditional use by wintering Piping Plovers (Nicholls and Baldassarre 1990, Haig and Plissner 1993)

The majority of radiotelemetry work was conducted on South Padre Island, however, data were also collected at wetlands associated with South Bay, Brazos Island, Laguna Atascosa National Wildlife Refuge, dredged material placement islands and mainland tidal flats adjacent to the Laguna Madre Surveys during 1998-1999 included the same areas

METHODS

Interannual Fidelity.

We conducted surveys for color-banded plovers returning to the southern Laguna Madre from 15 August 1998 through 15 May 1999 We conducted searches using four-wheel drive vehicles, all terrain vehicles, and by foot We also continued our investigation of roost site fidelity to determine if birds are philopatric to these sites Thus, we revisited roost sites that were regularly attended by banded and unbanded plovers during the 1997-1998 season to determine extent of fidelity between years

During searches for banded birds, we also recorded the number of Piping and

Snowy Plovers observed using habitats along the southern Laguna Madre. Upon resighting banded plovers, we recorded flock size, habitat type, and environmental variables. Habitat types include 1) dredged material placement areas (i.e., using habitats \leq approximately 100m of a DMPA island or impoundment, including use of periphery), 2) mudflats (i.e., mainland tidal flats) 3) lower sand flats (i.e., sand flats generally covered by the Laguna Madre and exposed only during low tides), 4) algal flats, 5) upper sand flats (located between algal flats and secondary dunes), and 6) beach habitats (located between the Gulf of Mexico and the primary dunes)

Extent of Piping Plover site fidelity was determined by overlaying 1998-1999 relocations over 1997-1998 polygons for individual birds. We used 1997-1998 radio and band relocations to calculate polygons of use during the 1997-1998 season. Polygons were created using the fixed kernel method in computer program KERNELHR. Smoothing parameters were determined by least squares cross validation and grid sizes selected automatically by the program to obtain the best fit. The percentage of 1998-1999 relocations that occurred within 1997-1998 polygons was used to determine fidelity rates.

Snowy Plover site fidelity was determined by calculating percent of individuals marked during 1997-1998 resighted during the 1998-1999 season. Polygons developed from the 1997-98 season were not calculated because the number of Snowy Plovers relocations were small ($n < 15$ relocations/bird, see Seaman et al. 1999)

We used a mark-recapture model to calculate a Piping Plover population estimate for the southern Laguna Madre using the resightings of color-banded Piping Plovers and overall counts of Piping Plovers during surveys.

We used Kruskal-Wallis ANOVA to test for differences in flock size among habitat types and tidal stages.

Habitat Use, Movements, and Home Range Size.

Capture and Marking

We captured Piping Plovers from mid August 1997 - February 1998 using a modified version of leg-snare traps (Bub 1991). Captured plovers were weighed to the

nearest gram, checked for intensity of body molt (0 = no pin feathers, 1 = < 5% pin feathers, 2 = 5 - 25% pin feathers, 3 = 26 - 50% pin feathers and 4 = > 50% pin feathers present) and flight-feather molt (none, asymmetric, or normal symmetric molt), fitted with a 1.2 g Holohil Systems Ltd BD-2G transmitter ($\leq 3\%$ of their body weight) epoxied to feathers in the intrascapular region (Knopf and Rupert 1995), and banded with a unique combination of ultraviolet protected color leg bands. We were able to externally age and/or sex only a small proportion of the birds we captured, therefore data were not analyzed relative to these parameters.

Radiotelemetry

We conducted searches for radio-marked birds throughout the life of their radio (approximately = 57 days). Successive relocations on individuals were spaced such that no two relocations occurred within the same daylight or nocturnal period. We used four-wheel drive vehicles, all terrain vehicles (ATVs), and foot searches to locate radio-marked plovers. When radio-marked Piping Plovers could not be located on the island and to facilitate nocturnal surveys, aerial surveys were used. We were able to get visual sightings of marked birds during most daylight relocations. If visual sightings were not possible due to low light levels or inability to access an area, we recorded direction of signal from at least 2 locations (< 15 m apart) and determined triangulated locations for birds using the computer program LOCATE (Kie et al 1994). We marked locations using a GARMIN Global Positioning System (GPS) Unit (95% accuracy ≤ 100 m). At time of relocation, we recorded the following variables when possible (i.e., during triangulations and aerial surveys some variables were not possible to collect): 1) date, 2) time, 3) behavior (foraging or roosting), 4) habitat type (i.e., lower sandflat, algal flat, upper sandflat, washover passes, beach, mud flat, DMPA, or other), 5) substrate moisture class (i.e., saturated [standing water present, or water surfaces when pressure is applied to substrate], wet [surface is notably wet but water does not surface with pressure on substrate], moist [surface appears dry but is wet when pressure is applied], or dry [no substrate moisture present]), 6) distance to and type of nearest water source and 7) tide level (recorded as the distance [+/-] from the mean high tide line – a noticeable line generally located between the algal flat/lower sandflat

interface)

Statistical Analyses

Chronology of molt and migration were used to delineate seasonal periods for nonbreeding Piping Plovers as follows fall (August 1997 to 30 November 1997) including prebasic molt following fall migration, winter (1 December 1997 to 15 February 1998) the non-molting period, and spring (16 February 1998 to 16 May 1998) the beginning of prealternate molt terminating with spring migration. Molt and migration were used to determine seasonal periods because birds sustain increased energy requirements during these events (King 1974, Walsberg 1983) and some evidence exists that shorebirds make regional movements in relation to molt (Pienkowski and Evans 1984).

Home ranges for 1997-1998 were recalculated using more rigorous analyses from those used in Zonick et al (1998). Zonick et al (1998) calculated home range estimates using the minimum convex polygon method that included areas plovers traversed but did not use (i.e. Laguna Madre). We reanalyzed 1997-1998 data by defining home range as the area used during normal activities for feeding and roosting. We calculated home range sizes using the program KERNELHR (Seaman et al 1998) based on the fixed kernel method (Worton 1989). Smoothing parameters were determined by least squares cross-validation (LSCV) (Worton 1995, Seaman and Powell 1996). Grid size was determined automatically by KERNELHR, so that scale could be adjusted according to each bird (Seaman et al 1998). We chose the fixed kernel technique for analysis because it is less biased than other commonly used home range estimators (see Anderson 1982, Harris et al 1990, Worton 1995, Seaman et al 1999).

We calculated overall home range size (averaged across seasons), as well as seasonal home range sizes, encompassing 95% and 50% of an individual's utilization distribution. To maintain independence between seasons, calculation of seasonal home ranges (for individuals with relocations in > 1 season) included only those relocations recorded within the first season containing ≥ 10 relocations. Home range calculations did not include individuals with < 10 relocations.

We used nonparametric statistics because home range sizes and movements did not meet the assumptions of normality (PROC UNIVARIATE, SAS Institute 1996) We compared mean home range size between seasons using Kruskal-Wallis one-way analysis of variance (PROC NPAR1WAY, SAS Institute 1996) Dunn's multiple comparison test (Dunn 1964) was used to determine where differences occurred if the overall Kruskal-Wallis test statistic was significant We obtained distances between successive relocations using CALHOME (Kie et al 1996) and calculated mean seasonal movements by averaging distances moved between successive relocations for individuals Habitats were categorized as mainland or barrier island then further subdivided as follows mudflat, lower sandflat, algal flat, upper sandflat, washover pass, beach, DMPA, or other We calculated overall frequency of occurrence (averaged across seasons) within each habitat type and overall frequency of soil moisture class for habitats used by radio-marked Piping Plovers (PROC FREQ, SAS Institute 1996) To gain insight on seasonal habitat use, we averaged individual frequency of occurrence for each habitat during each season (PROC FREQ and PROC MEANS, SAS Institute 1996) To maintain independence between seasons, calculation of habitat use (for individuals with relocations in > 1 season) included only those relocations recorded within the first season containing ≥ 10 relocations Seasonal comparisons did not include individuals with < 10 relocations We used Kruskal-Wallis one-way analysis of variance to test for seasonal differences in habitat use (PROC NPAR1WAY, SAS Institute 1996) and Dunn's multiple comparison test (Dunn 1964) to determine where differences occurred if the overall Kruskal-Wallis analysis of variance was significant. Because beach habitats were only used during fall and spring and DMPAs were used only during winter and spring, we used a Mann-Whitney U-test to determine if seasonal differences in use of these habitats existed

To better understand seasonal changes in habitat availability related to tide, we calculated seasonal mean tide levels using tide data Seasonal tide levels did not meet assumptions of normality; therefore, we made interseasonal comparisons of tide levels using a Kruskal-Wallis ANOVA Dunn's multiple comparison was used to determine where differences occurred if the Kruskal-Wallis test statistic was significant

We also calculated mean distance to water and frequency of occurrence (number of relocations) of nearest water source (i.e., pool or Laguna Madre). We then calculated percent of radio relocations in which radio-marked Piping Plovers were found foraging and roosting. However, due to sample size disparities between behaviors (see RESULTS), analyses of habitat differences between behaviors were not appropriate. Survival estimates were calculated as the number of transmitter days minus the number of mortalities /the total number of transmitter days (Heisey and Fuller 1985). All values reported in the RESULTS section are reported as means \pm standard error (SE).

Roosting Habitat of Piping and Snowy Plovers.

We located plover roost sites by conducting systematic surveys of habitats using binoculars and spotting scopes, and by relocating radio-marked Piping Plovers. Roosting was defined as a plover that was motionless (not locomoting), sitting or standing, often with their head tucked between their scapulars. Because individuals within roosting flocks often alternate between roosting and preening, we assumed all plovers found at roost site were selecting a microsite to roost within, and that preening bouts occurred between bouts of roosting.

Upon locating a roosting plover(s), number of roosting birds, species composition at the roost site, and bird orientation relative to wind direction (i.e., facing into the wind or other direction) were recorded. Roost sites were classified as follows: 1) Piping Plover roost, (sites containing only Piping Plovers or Piping Plovers roosted with species other than Snowy Plovers), 2) Snowy Plover roost, (site containing only Snowy Plovers or Snowy Plovers roosted with species other than Piping Plovers), and 3) interspecific roost, (site containing both Piping and Snowy Plovers roosted with or without other species). A 1 m² plot was centered at individual plover locations. In instances where plovers were < 1 m apart, the plot was centered on the mid-point between birds. For individual birds and roosts of up to five plovers, all locations > 1 m apart were sampled. When sampling flocks of more than five plovers, the five roost sites nearest the observer were sampled. Sampling the five nearest plovers was a

systematic approach to eliminating observer bias such as choosing individuals easiest to mark. For most plots, feces verified exact plover locations. Random 1 m² plots were located 50 m from the roost site at randomly selected cardinal directions (i.e., N, NE, E, SE, S, SW, W and NW). For roosts with more than one roost plot, an equal number of random plots were sampled. Random plots were juxtaposed such that they were situated at the same distance (m) and direction (determined by compass bearing) from each other as roost plots were.

To assess microhabitat features of roost sites, during the 1997-1998 season we measured percent areal coverage (rounded to the nearest 5% to reduce inter-observer variation) of the following variables within a 1 m² plot at individual bird locations: depressions, debris (e.g., senescent seagrass, wood, trash, etc.), shells, standing water, and vegetation (live vegetation and standing dead vegetation). When depressions were present, depression depth was documented. Soil moisture class was indexed as follows: 1) dry, 2) moist--substrate damp, water not brought to the surface when pressure was applied to substrate, 3) wet--water brought to the surface when pressure was applied to substrate, and 4) saturated--substrate surface visibly wet often with water pooled on the surface. These microhabitat features were also measured at random plots. To characterize macrohabitat features, we recorded the macrohabitat where roost sites occurred, and distance to water and vegetation.

We used nonparametric statistical procedures for analysis because data were not normally distributed (PROC UNIVARIATE NORM, SAS Institute Inc 1996). We used Mann-Whitney U-tests to compare microhabitat cover variables between roost and random plots, to make interspecific comparisons between microhabitat variables at Piping and Snowy Plover roost sites and to make interspecific seasonal comparisons between microhabitat variables (PROC NPAR1WAY, SAS Institute Inc 1996). We used descriptive statistics to determine mean distance of roost sites to water and vegetation, and proportions of plovers facing into the wind or other directions (PROC MEANS, SAS Institute Inc 1996). Finally, we compared mean distance to water and vegetation between roost and random plots, and between Piping and Snowy Plover roost sites using Mann-Whitney U-tests.

RESULTS

Interannual Fidelity.

Use of Dredged Material Placement Areas

During the 1998-1999 season we did not observe Piping or Snowy Plovers using dredged material placement areas. Low use of DMPAs remains consistent with plover use of dredged material placement areas during the 1997-98 field season.

Site Fidelity

Piping Plovers exhibited high fidelity to the southern Laguna Madre with 76% ($n = 38/50$) of Piping Plovers marked during 1997-1998 resighted during 1998-1999. Site fidelity occurred on a fine scale as 72.3% ($n = 318/440$) of 1998-1999 relocations were within 1997-1998 polygons. Snowy Plover fidelity was 61.3% ($n = 19/31$).

Plover Abundance and Piping Plover Population Estimate

Numbers of Piping and Snowy Plovers observed using habitats along the southern Laguna Madre increased from fall to winter and decreased as winter progressed into spring (Fig. 2 & 3). Counts of each species varied throughout winter, however, maximum winter counts were larger than those of fall and spring. Maximum counts were 531 and 285 for Piping and Snowy Plovers, respectively.

Piping Plover flock size ranged from 2 to 307. Piping Plover fall flock size ($\bar{x} = 6.61$, $SE = 1.53$) was smaller ($P \leq 0.02$) than both winter ($\bar{x} = 14.93$, $SE = 2.00$) and spring ($\bar{x} = 18.45$, $SE = 4.75$). Snowy Plover flock size ranged from 2 to 54. Snowy Plover flock sizes (fall $\bar{x} = 2.02$, $SE = 0.34$, winter $\bar{x} = 3.73$, $SE = 0.66$ and spring $\bar{x} = 3.07$, $SE = 0.89$) did not differ seasonally.

Estimated population size of Piping Plovers using habitats along the southern Laguna Madre is 871 (95% confidence interval 808-947).

Captive Reared Piping Plovers

During 1998-1999 we observed a captive reared Piping Plover (determined by light blue flag). This was the second sighting of a captive reared Piping Plover from the Northern Great Plains Army Corps of Engineers recovery program.

Figure 2 Number of Piping Plovers observed using habitats adjacent to the southern Laguna Madre from August 1998-May 1999

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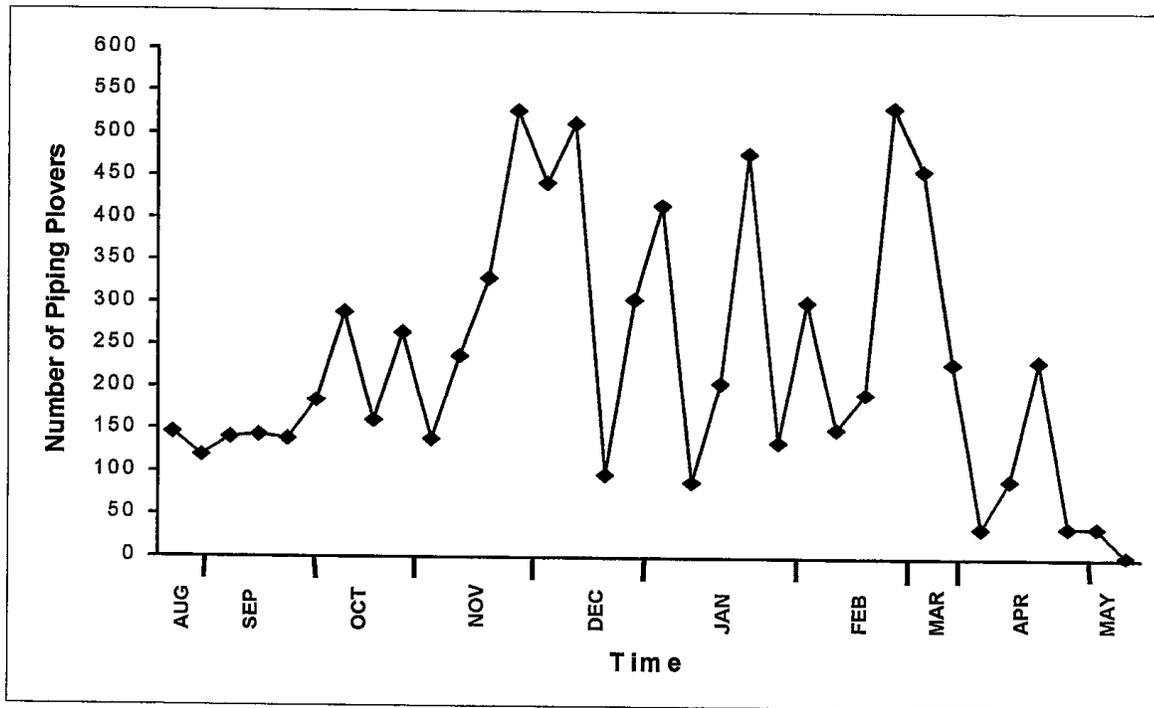
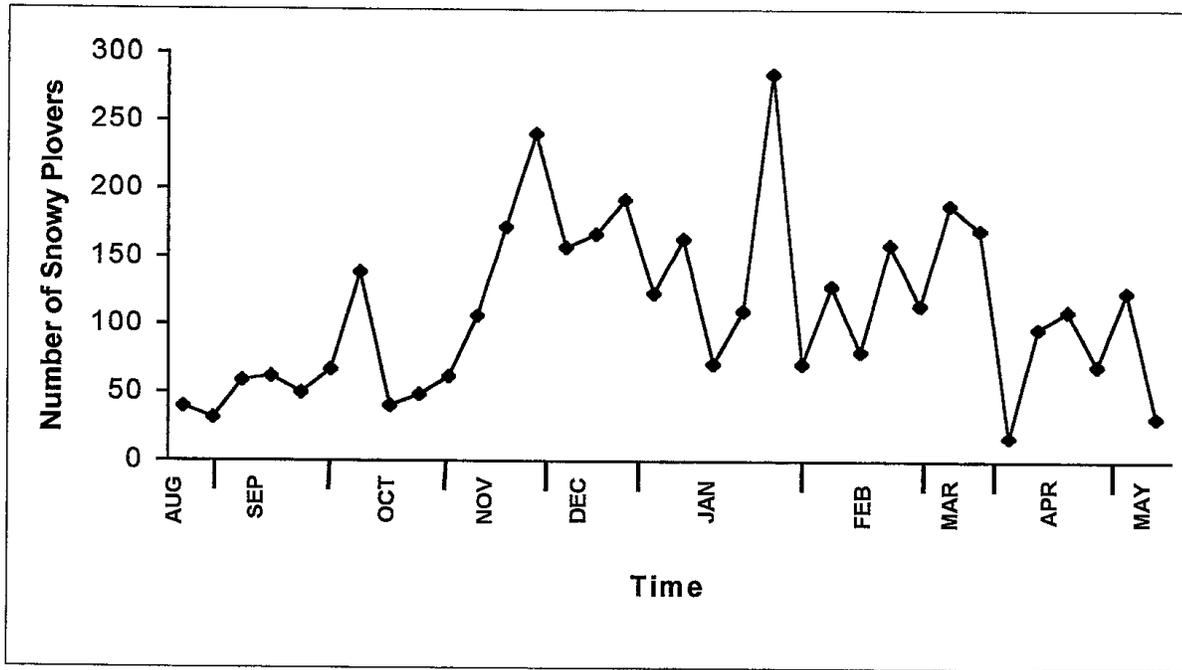


Figure 3 Number of Snowy Plovers observed using habitats adjacent to the southern Laguna Madre from August 1998-May 1999



Habitat Use, Survival, Home Range Size and Movements.

Habitat Use and Survival

No radio-marked Piping Plovers were found outside of the southern Laguna Madre throughout the 1997-1998 study period. The majority of relocations occurred on algal flats (50.5%) and lower sand flats (23.2%). Other, less commonly used habitats or areas, included washover passes (9.4%), upper sand flats (7.1%), mud flats (5.7%), beach (2.8%), dredged material placement areas (0.8%), and roadside ditches (0.5%). Piping Plovers used habitats with saturated (71.9%) or wet substrates (16.5%) most often and habitats with moist (8.8%) and dry substrates (2.8%) less often.

Seasonal habitat use by nonbreeding Piping Plovers is summarized in Table 1. Piping Plovers used algal flats more during fall ($P < 0.002$) and spring ($P < 0.001$) than winter. Additionally, use of beach habitat during fall was greater than spring ($P = 0.007$). Use of lower sand flats was more frequent during fall ($P = 0.039$) than spring and more frequent during winter than fall ($P < 0.001$) and spring ($P < 0.001$). Use of some habitat types was restricted to certain seasons. Roadside ditches were used only during fall and use of DMPAs occurred only during winter and spring (Table 1). Piping Plovers were found in close proximity ($\bar{x} = 20.8$ m, $SE = 1.75$ m, $n = 941$ relocations) to water. When Piping Plovers were using bayshore habitats, nearest water source was most often water pooled on the substrate's surface (55.5%), followed by the Laguna Madre (39.6%), and ponds within washover passes (4.9%). When Piping Plovers used beach habitats, the nearest water source was always the Gulf of Mexico. Lastly, tides were lower during winter ($\bar{x} = -98.5$ m, $SE = 14.8$ from algal flat/lower sand flat interface, $n = 314$ observations) than fall ($\bar{x} = 57.4$, $SE = 19.2$, $n = 169$ observations, $P < 0.001$) and spring ($\bar{x} = -8.5$, $SE = 9.9$, $n = 513$ observations, $P < 0.001$). Survival rates for Piping Plovers wintering along the southern Laguna Madre were 100% ($n = 49$ birds).

Home Range Size and Movements

We radioed and monitored 49 Piping Plovers between 10 August 1997 and 25 April 1999. One bird was recaptured and fitted with a second transmitter after the first was lost during prebasic molt. All birds were released within 15 minutes of capture. A total of 1,371 relocations were made on radio-marked Piping Plovers, averaging 29.6

Table 1 Mean percent Seasonal habitat use (percent of relocations) by Piping Plovers wintering along the southern Laguna Madre of Texas, August 1997 - April 1998

Habitat	Season Effects		Fall (n = 13) ^a		Winter (n = 14)		Spring (n = 19)	
	χ^2 ^b	P - value ^c	\bar{x}	SE	\bar{x}	SE	\bar{x}	SE
Algal Flat	18.98	0.000	53.5 A	5.1	29.8 B	3.1	58.8 A	3.3
Lower Sandflat	32.88	0.000	19.3 A	3.1	53.7 B	3.2	8.8 C	1.3
Upper Sandflat	2.23	0.316	9.0 A	2.5	5.0 A	2.2	6.7 A	2.9
Beach	9.92	0.007	7.0 A	3.3	0.0 B	0.0	1.3 AB	0.8
Wash Over	2.88	0.237	6.3 A	2.7	3.9 A	2.5	12.1 A	3.5
Mud Flat	2.55	0.279	1.6 A	0.9	5.6 A	2.2	10.9 A	4.6
Road-side Ditch	2.53	0.281	3.4 A	3.4	0.0 A	0.0	0.0 A	0.0
DMPA ^d	3.49	0.175	0.0 A	0.0	2.1 A	2.1	1.4 A	0.8

^a Number of birds

^b Kruskal-Wallis test statistic for seasonal differences in habitat use. Results from unplanned multiple comparison tests are given using capital letters near mean percent of habitat use. Values with different letters differ within each row.

^c Overall probability from Kruskal-Wallis test that use of habitat differs seasonally.

^d Dredge material placement area.

(SE = 1.3) relocations per individual

Mean home range size of Piping Plovers at the 95% utilization distribution (hereafter referred to as home range) was 1,262 ha (SE = 326, $n = 48$ birds). Mean core area at the 50% utilization distribution (hereafter referred to as core area) was 2943 ha (SE = 79, $n = 48$ birds). Home range size was smaller ($P = 0.012$) during fall ($\bar{x} = 588$, SE = 153 ha, $n = 13$ birds) than in winter ($\bar{x} = 1,774$, SE = 374 ha, $n = 14$ birds). Spring home range size ($\bar{x} = 1,112$, SE = 272 ha, $n = 19$ birds) did not differ from fall ($P = 0.112$) or winter ($P = 0.482$). Core areas showed similar trends in seasonal differences. Core areas were smaller ($\bar{x} = 144$ ha, SE = 38 ha, $n = 13$ birds) in fall than winter ($\bar{x} = 433$ ha, SE = 101 ha, $n = 14$ birds). Core areas in spring ($\bar{x} = 259$ ha, SE = 64 ha, $n = 19$ birds) did not differ from winter ($P = 0.510$) or fall ($P = 0.168$).

Mean linear distance moved per individual (distances moved averaged across seasons) was 3,294 m (SE = 475, $n = 48$ birds). Mean distance moved per individual was smaller during fall ($\bar{x} = 1,914$ m, SE = 403 m, $n = 13$ birds) than both winter ($\bar{x} = 4,195$ m, SE = 588 m, $n = 14$ birds, $P = 0.002$) and spring ($\bar{x} = 3,637$ m, SE = 532 m, $n = 19$ birds, $P = 0.013$).

Radio-marked Piping Plovers were found foraging during 90.8% of relocations (939/1034) and roosting during the remaining 8.2% (95/1034). Piping Plovers seldom used tidal flats adjacent to developed areas (5/1371 relocations). Survival rates for Piping Plovers wintering along the southern Laguna Madre were 100% ($n = 49$ birds).

Roosting Habitat of Piping and Snowy Plovers.

We sampled 42 Piping Plover ($n = 120$, number of plots), 39 Snowy Plover ($n = 119$) and 19 interspecific roost sites ($n = 53$, Piping Plover and $n = 45$ Snowy Plover). The majority (94%) of roost sites occurred on algal flats and upper sand flats. Algal flats were the predominant roost habitat containing 65% of roost sites, while upper sand flat was the second most commonly used macrohabitat with 29% of roost sites.

Plovers typically roosted individually or in small flocks facing into the wind (83.4% and 84.8% of Piping and Snowy Plovers, respectively, oriented into the wind). Piping

Plover roost sites averaged 4.60 ± 0.65 Piping Plovers/roost site, while Snowy Plovers roost sites averaged 3.95 ± 0.78 Snowy Plovers/roost site. Interspecific roost sites averaged 4.79 ± 1.09 Piping Plovers and 3.84 ± 0.76 Snowy Plovers. Other species found roosting with Piping and Snowy Plovers were Sanderlings (*Calidris alba*), Dunlins (*Calidris alpina*), Western Sandpipers (*Calidris mauri*), Least Sandpipers (*Calidris minutilla*), Ruddy Turnstones (*Arenaria interpres*), Semipalmated Plovers (*Charadrius semipalmatus*), Wilson's Plovers (*Charadrius wilsonia*) and Black-bellied Plovers (*Pluvialis squatarola*).

There was considerable variation between microhabitat characteristics of roosts and random plots for both Piping and Snowy Plovers (Tables 2 and 3). Piping Plover roost sites had more areal coverage of depressions ($P = 0.004$) and debris ($P < 0.0001$), less standing water ($P < 0.0001$), deeper depression depth ($P < 0.0001$) and drier substrate than random plots ($P = 0.049$) (Table 2). Snowy Plover roost sites had more areal coverage of depressions ($P < 0.0001$) and debris ($P < 0.0001$), less standing water ($P = 0.047$), deeper depression depth ($P < 0.0001$) and drier substrate than random plots ($P = 0.012$) (Table 3).

Interspecific comparisons of roost site characteristics revealed differences in microhabitat use by roosting Piping and Snowy Plovers (Table 4). Snowy Plover roosts had greater coverage of depressions ($P = 0.0014$) and debris ($P = 0.0039$), and deeper depression depth ($P = 0.022$) than Piping Plover roosts. In contrast, Piping Plover roosts had more vegetation ($P = 0.003$) than Snowy Plover roosts. Piping Plover roosts were also closer to water ($P < 0.0001$) and adjacent vegetation ($P < 0.0001$). Seasonal comparisons between Piping and Snowy Plover roost sites revealed seasonal variation in microhabitat differences. Piping Plover roosts had less coverage of depressions during fall and spring ($P < 0.05$), less debris during winter and spring ($P < 0.005$), and shallower depressions during winter ($P < 0.0001$) than Snowy Plover roosts. Additionally, substrate at Piping Plover roosts was wetter than Snowy Plover roosts during spring ($P = 0.03$).

Table 2. Comparison of microhabitat characteristics at wintering Piping Plover roosts ($n = 173$) and random sites ($n = 173$) along the southern Laguna Madre of Texas, 1997-1998

Cover variable	Piping Plover		P^a	Random	
	\bar{x}	SE		\bar{x}	SE
Depressions (%) ^b	21.52	1.65	0.0036	15.99	1.63
Debris (%)	18.81	1.99	0.0001	4.91	0.88
Shell (%)	2.85	0.51	0.7320	3.21	0.53
Water (%)	1.50	0.65	0.0001	18.16	2.63
Vegetation (%)	0.13	0.04	0.0945	0.51	0.43
Depression depth (cm)	2.81	0.16	0.0001	1.39	0.11
Soil moisture ^c	2.58	0.08	0.0490	2.81	0.09
Distance to water (m)	38.30	3.58	0.9586	50.64	4.72
Distance to vegetation (m)	237.02	29.31	0.8304	236.60	29.39

^a Probability from Mann-Whitney U-test that adjacent means did not differ.

^b Percent areal cover within 1 m² plot

^c Mean soil moisture class (1 = dry, 2 = moist, 3 = wet and 4 = saturated).

Table 3. Comparison of microhabitat characteristics at wintering Snowy Plover roosts ($n = 164$) and random sites ($n = 164$) along the southern Laguna Madre of Texas, 1997-1998

Cover variable	Snowy Plover		P^a	Random	
	\bar{x}	SE		\bar{x}	SE
Depressions (%) ^b	28.11	1.70	0.0001	13.29	1.31
Debris (%)	33.89	2.92	0.0001	6.75	1.20
Shell (%)	1.81	0.31	0.9285	2.42	0.53
Water (%)	2.03	0.62	0.0437	9.93	2.12
Vegetation (%)	0.07	0.06	0.1699	0.00	0.00
Depression depth (cm)	3.31	0.16	0.0001	1.73	0.33
Soil moisture ^c	2.42	0.08	0.0490	2.73	0.09
Distance to water (m)	61.21	4.13	0.8289	67.88	5.06
Distance to vegetation (m)	321.58	31.05	0.1039	303.59	34.41

^a Probability from Mann-Whitney U-test that adjacent means did not differ

^b Percent areal cover within 1 m² plot

^c Mean soil moisture class (1 = dry, 2 = moist, 3 = wet and 4 = saturated)

Table 4 Comparison of microhabitat characteristics at wintering Piping Plover ($n = 173$) and Snowy Plover roosts ($n = 164$) along the southern Laguna Madre of Texas, 1997-1998

Cover variable	Piping Plover		P^a	Snowy Plover	
	\bar{x}	SE		\bar{x}	SE
Depressions (%) ^b	21.52	1.65	0.0014	28.11	1.70
Debris (%)	18.81	1.99	0.0039	33.89	2.92
Shell (%)	2.85	0.51	0.6145	1.81	0.31
Water (%)	1.50	0.65	0.1879	2.03	0.62
Vegetation (%)	0.13	0.04	0.0034	0.07	0.06
Depression depth (cm)	2.81	0.16	0.0222	3.31	0.16
Soil moisture ^c	2.58	0.08	0.1544	2.42	0.08
Distance to water (m)	38.30	3.58	0.0001	61.21	4.13
Distance to vegetation (m)	237.02	29.31	0.8304	321.58	31.05

^a Probability from Mann-Whitney U-test that adjacent means did not differ

^b Percent areal cover within 1 m² plot

^c Mean soil moisture class (1 = dry, 2 = moist, 3 = wet and 4 = saturated)

DISCUSSION

1998 – 1999, Fidelity and Population Estimate

Contrary to previous belief (Haig 1993), once Piping Plovers arrive along the southern Laguna Madre most birds remain throughout the nonbreeding period. High interannual fidelity emphasizes the importance of the southern Laguna Madre to wintering Piping Plovers.

The majority of Piping Plovers wintering along the southern Laguna Madre breed in the Great Plains and Great Lakes regions (Haig and Oring 1988, this study). The population estimate from this study indicates that 16% of the entire population of Piping Plovers depend upon habitats adjacent to the southern Laguna Madre throughout the nonbreeding period. Importantly, the majority of Piping Plovers wintering along the southern Laguna Madre originate from inland breeding populations (Haig and Oring 1988, this study). Therefore, conservation of tidal flats adjacent to the southern Laguna Madre may be crucial to the population since 25% of all Piping Plovers using inland breeding habitats (871/3,520 [inland breeding population = 64% of entire population, Haig and Plissner 1993]) use habitats adjacent to the southern Laguna Madre.

Home Range, Habitat Use, Movements and Survival

Home Range, Habitat Use and Seasonal Movements

Seasonal home range size and movements were likely affected by both habitat and prey availability. During early fall (August – mid-September), hot temperatures and lack of precipitation resulted in desiccation of algal flats. Furthermore, prevailing southeasterly winds created seiches that prevented the saturation of algal flats through tidal inundation. Because substrate desiccation decreases invertebrate availability (Pienkowski 1981, Pienkowski 1982, Withers 1994), overall availability of foraging habitats was reduced. Offering further support that the algal flat was not as productive in early-fall, was higher use of lower sand flat in fall than spring. Even though fall tides were relatively higher than spring tides, Piping Plovers relied on lower sand flat during this period because it was the only saturated bayshore habitat available. Furthermore, use

of lower sand flat during fall occurred most often in August – mid-September. Additionally, hot temperatures and lack of precipitation cause salinity levels to peak in the Laguna Madre during late summer to early fall (Breuer 1962, Hedgepeth 1967, Withers 1994) Because increasing salinity results in an overall decline of invertebrate abundance and diversity (Simmons 1957, Copeland and Jones 1965, Ferraris et al 1994, Withers 1994), Piping Plovers may have restricted movements to habitats along more southern portions of the southern Laguna Madre where salinity is lower, thus, improving foraging opportunities Searches along more northern portions of South Padre Island (\geq 15 Km north of Brazos Santiago Pass) during trapping attempts in early fall 1997 found no Piping Plovers using these habitats Furthermore, Piping Plovers radioed in early fall remained on southern portions of the island ($<$ 15 Km from Brazos Santiago Pass) These same birds were later resighted by color bands in late fall and winter using more northern habitats

Although availability of productive habitats were limited during early fall, prey resources were adequate to meet energetic demands or plovers would have been forced to migrate from the area Furthermore, territorial aggression was greatest during fall (Drake 1999) indicating that prey availability was not limited or territories would not have been profitable (Myers et al. 1979) Occurrence of territoriality probably also contributed to shorter fall movements If Piping Plovers were to increase movements, they could lose established territories and expend more energy searching for and establishing a second territory than remaining in the same area where food resources were adequate

During late fall (mid-September - October), increased precipitation coincided with seasonally high tides that reduced habitat availability by inundating tidal flats Increased precipitation and frequent inundation saturated algal flats, increasing invertebrate diversity and abundance (Withers 1994) leading to the subsequent high of algal flats by Piping Plovers during fall (Table 1) Lower sand flats were used less often during late fall because they were generally unavailable When tidal fluctuations submerged algal flats and upper sand flats on the island and tidal flats adjacent to the mainland, Piping Plovers were forced to use beach habitats Reduction of available

habitats curtailed Piping Plover movements throughout much of the remaining fall period. Consequently, use of beach habitat was most frequent during fall (Table 1) and only occurred when bayshore habitats were unavailable.

During winter, movements and home range size of Piping Plovers increased concurrently with seasonal low tides that exposed lower sand flats. Without regular tidal inundation, the algal flat was typically desiccated during winter. Substrate desiccation results in decreased invertebrate availability (Pienkowski 1981, Withers 1994), explaining the shift in habitat use from algal flats to freshly exposed lower sand flats. Additionally, changes in weather patterns contributed to larger winter movements. Seiches created by strong north winds often inundated lower sand flats and occasionally algal flats on the island while exposing tidal flats adjacent to the mainland. With desiccation of algal flats and lower sand flats unavailable, Piping Plovers moved to mainland tidal flats. Initial use of mainland tidal flats coincided with occurrence of the first northern storm front. During both winter and spring, Piping Plovers used mainland habitats, which contributed to larger movements and home range size during these periods.

Seasonal high tides during spring regularly inundated algal and upper sand flats, consequently, availability of lower sand flats was reduced and algal flats were frequently saturated. Thus, high use of algal flats during spring likely occurred when saturated substrates increased invertebrate availability (Pienkowski 1981, Withers 1994). Interestingly, although habitat availability decreased, spring movements and home range size remained large probably due to migratory restlessness and conditioning flight muscles in preparation for migration.

Bayshore tidal flats appear to be preferred over beach habitat by nonbreeding Piping Plovers. It is possible that greater amounts of human disturbance associated with beach habitats limited use of these areas (see Burger 1994) but, if this were the primary factor, Piping Plovers should have used beach habitats on northern portions of South Padre Island where disturbance occurs less frequently. Conversely, use of beach habitats was less on northern portions of the island where bayshore tidal flats are widest, suggesting that bayshore habitats yield higher benefits than beach habitats.

Greater use of bayshore tidal flats is likely due to better foraging conditions associated with high productivity of algal flats and bayshore intertidal areas (see Withers 1994), more extensive tidal flats, and more stable water lines. Frequent inundations and exposure often left up to 1 km in width of saturated bayshore habitats available for foraging Piping Plovers. Although the tidal regime within the Laguna Madre is dynamic because of wind influences on tides, wave action is minimal relative to beach habitats. Along bayshore habitats, Piping Plovers foraged most often near shallow pools on exposed tidal flats where movements at a particular site were minimized. In contrast, within beach habitats, the wave action zone generally provided only a narrow width (generally < 10 m) of foraging habitat, and foraging efficiency is likely be lessened on beach habitats by increased movements necessary for foraging within the wave action zone (running back and forth to avoid waves).

Foraging was the primary activity for wintering Piping Plovers (see also Johnson and Baldassarre 1988, Nicholls and Baldassarre 1990, Drake 1999) and typically occurred on bayshore tidal flats. However, the importance of beach habitats should not be underrated, as beaches provided important foraging habitats when bayshore tidal flats were unavailable. Tidal flats adjacent to the Laguna Madre support large numbers of wintering Piping Plovers (Nicholls and Baldassarre 1990, Haig and Plissner 1993, This Study) and provide important habitats because foraging areas remain available throughout the non-breeding period, regardless of tidal cycle. Movement patterns revealed that Piping Plovers use all tidal habitats including beaches and mainland tidal flats. Because not all habitat types are available or productive at any one time, plovers must depend upon different habitat types throughout the nonbreeding period, emphasizing the importance of conserving a mosaic of tidal habitat types.

Survival

As with most shorebirds, high winter survival is critical to the survival of the species because overall fecundity rates are low (Myers et al 1987). Piping Plovers lay 3-4 egg clutches, typically raising only one brood per season (Wilcox 1959, Cairns 1982, Haig and Oring 1988), however, double brooding may occasionally occur.

(Bottitta et al 1997) Because, adult survival has the greatest effect on population growth (Schmutz et al 1997), if adult survival was reduced, particularly for species with low fecundity rates, extirpation of the species would eventually occur (Ryan et al 1993)

Piping Plover mortality is probably highest during the breeding season, because nesting birds are more susceptible to predation (Sargeant and Raveling 1992) Therefore, high winter survival rates are necessary to increase population levels The current annual survival estimate of Piping Plovers (66%) was based on fidelity rates of birds returning to breeding areas in the Great Plains (Root et al 1992) However, survival estimates based on mark-recapture techniques are biased low (Schmutz et al 1997) Telemetry data from this study indicates that overwinter survival of Piping Plovers is probably higher than those reported by Root et al (1992) and suggests population declines are due to low hatching success and brood survival on breeding areas

Roosting Habitat of Piping and Snowy Plovers.

Plovers generally roosted within depressions or on the leeward side of mounded debris, presumably seeking shelter from wind to minimize convective heat loss Deeper depression depth within roost plots supports the assertion that shelter from wind is a factor contributing to microsite selection by roosting plovers Microsite selection is important to an animal's thermal ecology because small changes in wind velocity can have dramatic effects on an animal's thermal balance (Walsberg 1986). Furthermore, wind penetration into plumage increases heat loss (Walsberg 1986) and most roosting plovers orient into the wind, which would reduce wind penetration into their plumage Because tidal flats are generally open, unvegetated habitats, irregularities in topography and debris deposited on tidal flats provide most of the available refugia

An alternate explanation, though not mutually exclusive from seeking shelter, is that plovers select microsites that reduce predation risks Tidal flat substrate color was relatively homogeneous within macrohabitat types with exception of debris and shells on the substrate surface Debris break up the color continuity of substrates and make

substrate surfaces irregular and these factors likely benefit roosting plovers by aiding their concealment. The primary debris component was senescent seagrass (*Halodule wrightii*, *Thalassia testudinum* and *Syringodium filiforme*) deposited on the upperflats (algal and upper sandflats) by high tides and wind. Senescent seagrass ranged in color from bleached white to brown, similar in color to plumage of plovers. Depressions and debris provided concealment making roosting plovers difficult to find. Generally, roosts contained both depressions and debris; thus, plovers likely gain shelter from wind and concealment from predators concurrently.

Concealment benefits gained by roosting in association with depressions and debris are probably more important in avoiding detection by avian rather than mammalian predators. Because tidal flats are open habitats, it is unlikely that mammalian predators, such as coyotes (*Canis latrans*), pose a significant threat to roosting shorebirds. Plovers generally roosted > 100 m from coastal prairie further reducing risk of successful attacks by mammalian predators. Page and Whitacre (1975) found that raptors depredated nearly 10% of Dunlin and 7% of Killdeer (*Charadrius vociferus*) winter populations at Bolinas Lagoon, California. Similarly, Peregrine Falcons (*Falco peregrinus*) are likely the primary predator on plovers wintering along the southern coast of Texas. Peregrine Falcons migrate through the southern Laguna Madre region in large numbers (Hunt et al. 1975) and were consistently seen hunting tidal flats during the study period. Falcons generally attack prey while in flight, however, we observed falcons stooping at foraging shorebirds and capturing them as they took flight. Typical response of a foraging plover to a Peregrine Falcon was to flatten itself to the ground and remain in this posture until the falcon left the area (K. L. Drake 1999). Because plovers did not take flight to avoid falcons, benefits of concealment are likely gained by roosting in association with depressions and debris.

Piping and Snowy Plovers were often found together at roost sites, selecting similar microhabitat characteristics. Although Snowy Plovers sites were associated with more depressions and debris, at the microsite level, lower amounts of these variables associated with Piping Plover roosts still would appear to provide the presumed concealment benefits.

Differences in microhabitat variables might also be explained from a functional role of providing a favorable microclimate. Smaller bodied Snowy Plovers have higher surface-area-to-mass ratio than Piping Plovers (Aschoff and Pohl 1970). Greater amounts of debris found at Snowy Plovers roosts may be related to thermoregulation because as plant biomass decays it produces heat. Additionally, roosting in deeper depressions by Snowy Plovers may be important in reducing metabolic costs caused by exposure to wind. Although the difference of 0.5 cm seems miniscule, to a small plover, this amount may shelter a significant portion of its body. These explanations are supported by the interspecific seasonal comparisons because the differences occurred during seasons with cooler temperatures.

Habitat selection involves choice of a particular habitat from available habitats resulting in non-random distribution of animals (Burger 1987). Piping and Snowy Plovers typically roosted on algal flats and upper sand flats, while selecting for individual roost sites based on microhabitat characteristics. Typically, shorebirds make predictable movements between foraging areas and roosting locations (Myers 1980, Swennen 1984, Warnock and Takekawa 1996), however, complete inundation of foraging habitats along the bayshore of the southern Laguna Madre seldom occurs. Tidal flats along the southern Laguna Madre are unique in their vastness and in juxtaposition of differing habitat types. Plovers often foraged within the same habitats they roosted, thus, selecting roost sites at the microsite level allows plovers to seek cover and concealment while remaining near or within foraging areas.

CONSERVATION IMPLICATIONS and MANAGEMENT RECOMENDATIONS

Interannual Fidelity

Knowledge that 25% of the entire inland breeding Piping Plover population spends at least 75% of their annual cycle wintering along the southern Laguna Madre stresses the importance of conserving tidal flats adjacent to the southern Laguna Madre. High winter philopatry to specific areas emphasizes the importance of specific sites for individual plovers. This is further highlighted when considering the large numbers of Piping Plovers that depend upon these habitats.

Habitat Use, Movements, and Survival.

Dredged Material Placement Areas

Currently, some of the dredged material within the southern Laguna Madre is disposed of by placing the material in leveed placement areas on mainland tidal flats. Tidal flats adjacent to shipping channels (primarily the mouth of Arroyo Colorado and the Brownsville Ship Channel) have been altered by building dikes around the perimeter of impoundment sites and filling areas with freshly pumped dredged materials. Conversion of mainland tidal flats to dredged material impoundments will result in a net loss of habitat for wintering Piping Plovers because impoundments eventually revert to upland habitat. Piping Plovers used dredged material islands during both winter and spring of 1997-1998, however, use of these islands was restricted to outer exposed edges directly influenced by tidal inundation. Although creating dredged material islands is no longer used as a disposal technique, dredged material placement islands continue to impact mainland tidal flats. Through time, islands have coalesced to create barriers that alter the natural regime of inundation and exposure on adjacent mainland tidal flats. Consequently, these areas revert to upland habitat (T. Cooper pers. com., C. Zonick pers. com.). It is important to note that effective management for Piping Plovers must include control of vegetation (Haig 1992) and that wintering Piping Plovers did not use dredge impoundments or other vegetated areas.

Low use of dredged material placement areas by radioed Piping Plovers was consistent with findings of Espey, Huston & Associates, Inc (EH&A) Piping Plover DMPA surveys (EH&A 1996, EH&A 1997). EH&A surveys of DMPAs 3 and 4A (adjacent to the Portmansfield Ship Channel) found 35 Piping Plovers using habitats adjacent to DMPAs, with no Piping Plover use of DMPAs (all birds were 400m – 1km from edge of placement) (see maps within EH&A 1996). Additional EH&A surveys of DMPAs, encompassing approximately 34 km of Gulf Intracoastal Waterway (GIWW) from the land cut to Port Isabel Bay, also found no Piping Plover use of DMPAs (EH&A 1997).

More extensive movements that encompassed mainland tidal flats during winter

and spring indicate that bayshore tidal flats are important to wintering Piping Plovers. When island bayshore tidal flats were inundated during fall, Piping Plovers used beach areas directly adjacent to areas of bayshore use. Mainland tidal flats were probably not used during fall because they were generally unavailable to Piping Plovers. During early fall, southeastern winds inundated mainland tidal flats and during late fall increased precipitation combined with high tides and caused these areas to remain inundated. During winter and spring when seiches inundated and exposed mainland tidal flats, Piping Plovers made larger movements to mainland tidal flats.

Beneficial uses of dredged material for creating or enhancing habitat for winter Piping Plovers is difficult to conclude upon. Disposal of dredged material within leveed impoundments on tidal flats or other methods that disrupt normal tidal regimes will result in net loss of Piping Plover winter habitat. Alternative methods that do not involve use of leveed impoundments on tidal flats should be maintained. It is further recommended dredge disposal techniques that alter salinity levels (i.e., creating fresh water marshes) be avoided, because Piping Plovers do not use fresh water habitats (Haig and Plissner 1993, Nicholls and Baldassarre 1990). Conversion of saline tidal flats into fresh water marshes would result in further loss of wintering Piping Plover habitat.

This study reveals no evidence that unconfined disposal of dredged material within the bay system is harmful to Piping Plovers. However, if seagrass beds are negatively affected by unconfined disposal of dredged material, long-term effects of this disposal method may potentially impact Piping Plovers. Because seagrass beds are a source of detritus in the food chain of tidal flats, their presence may influence invertebrate diversity, abundance, and availability. We recommend further studies address possible dredging impacts on polychaets and other invertebrates consumed by Piping Plovers (Zonick unpubl. data). These studies should conclude upon diversity, abundance, and depth (availability) of invertebrates within dredged and undredged areas, while accounting for differences in salinity levels.

Seasonal Movements and Habitat Use

Future surveys to establish use of an area by wintering Piping Plovers (i.e.,

determination of environmental impact assessments) should include monitoring an area for the entire nonbreeding period because of seasonal movements and changes in habitat use by wintering Piping Plovers. Piping Plovers cycle among different habitat types depending upon seasonal habitat availability. If surveys are restricted to a small time period, surveys may not document use of the area by Piping Plovers, although the habitat may be important during other periods.

Demographic Effects of Survival Rates

Annual survival of Piping Plovers has been estimated at 66% based on birds breeding in the Great Plains (Root et al. 1992). No mortalities of radio-marked Piping Plovers wintering along the southern Laguna Madre suggests that winter mortality in subtropical regions is probably not a factor contributing to the population decline. However, because winter body condition can influence annual survival in some birds (Haramis et al. 1986), increased disturbance or loss of winter habitat could cause Piping to alter movement patterns (Goss-Custard 1979), resulting in dispersal to suboptimal habitats (Myers et al. 1987, Burger 1994). Smaller home range size and higher rates of Piping Plover aggression during fall when habitat was most limiting (K. L. Drake 1999) suggests that competition may periodically occur on wintering areas (Myers and McCaffery 1984, K. L. Drake 1999). Movements seldom encompassed tidal flats adjacent to the town of South Padre Island, suggesting that Piping Plovers are susceptible to disturbance. If individuals are forced to compete more for less habitat due to continuing loss of tidal flats and the subsequent increase in disturbance, survival and overall fitness of wintering Piping Plovers could decline.

Roosting Habitat of Piping and Snowy Plovers.

We made no attempt to quantify use of natural versus man-made depressions, although plovers readily used both types. Plovers were often found roosting in tire tracks and footprints, and depressions caused by human activities probably provide a favorable microclimate for roosting plovers. Plover roost sites were generally found within or near foraging areas. These foraging areas were predominately tidal flats in which the benthic prey base depends upon a regime of tidal inundation and exposure.

Disturbances to the substrate surface, such as vehicle tracks or other unnatural depressions, may have adverse effects on the hydrology of tidal flats. In particular, areas that receive frequent vehicular traffic have well developed 'two-tracks' and often the tire tracks need to fill with water before the adjacent tidal flats are inundated. Furthermore, sediment impaction may have adverse effects on benthic fauna.

Further consideration should be given to protecting seagrass beds within the Laguna Madre. Seagrass deposited on tidal flats was almost always present at plover roost sites providing an additional example of the importance of seagrass to the lagoon system. Availability of seagrass for shelter and concealment may influence site use and ultimately survival of wintering plovers.

Tidal flats along the southern Laguna Madre are vast compared to other areas within Piping and Snowy Plover nonbreeding distributions. Plovers wintering along the southern Laguna Madre generally use bayshore tidal flats throughout the nonbreeding period (K. R. Drake 1999). The regime of tidal inundation and exposure is dynamic and less predictable than most coastal areas due to wind seiches. Throughout the majority of the nonbreeding period foraging habitat is available at any given time because as tidal flats on one side of the lagoon are inundated the other side is exposed. Plovers wintering along the southern Laguna Madre do not appear to make extensive movements between roosting and foraging areas, rather they roost in the immediate vicinity of, or within, their primary foraging habitats (K. R. Drake 1999). This illustrates how the conservation of limited habitats is not adequate for conservation of plover populations, but emphasizes the importance of conserving a mosaic of habitat types.

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APPENDIX A.

Piping Plover home range polygons overlaid on a satellite image of the southern Laguna Madre of Texas. Home range polygons include only radio-transmitter relocations during the 1997-1998 field season. Observations of non-radioed birds (i.e., after radios were lost during molt or radio battery failed) are not included within polygons, as observational relocations may bias habitat use to areas that are more assessable to observers.

*Note: Software programs that create polygons within linear habitats (i.e., tidal flats of barrier islands) can sometimes create contour lines that are slightly outside of the linear habitat (see Figure 42a, relocation on Gulf of Mexico shoreline). This is due to the algorithms used in creating the contours (E. Seaman pers. com.). All relocation points were within the correct habitat and polygons still represent the appropriate area. Polygons encompassing GIWW areas are correct, as these birds were relocated when using dredged material placement islands and impoundments on mainland shores (i.e., See Figure 44a).



Figure 1a. Home range of Piping Plover #177



Figure 2a Home range of Piping Plover #219



Figure 3a Home range of Piping Plover #248

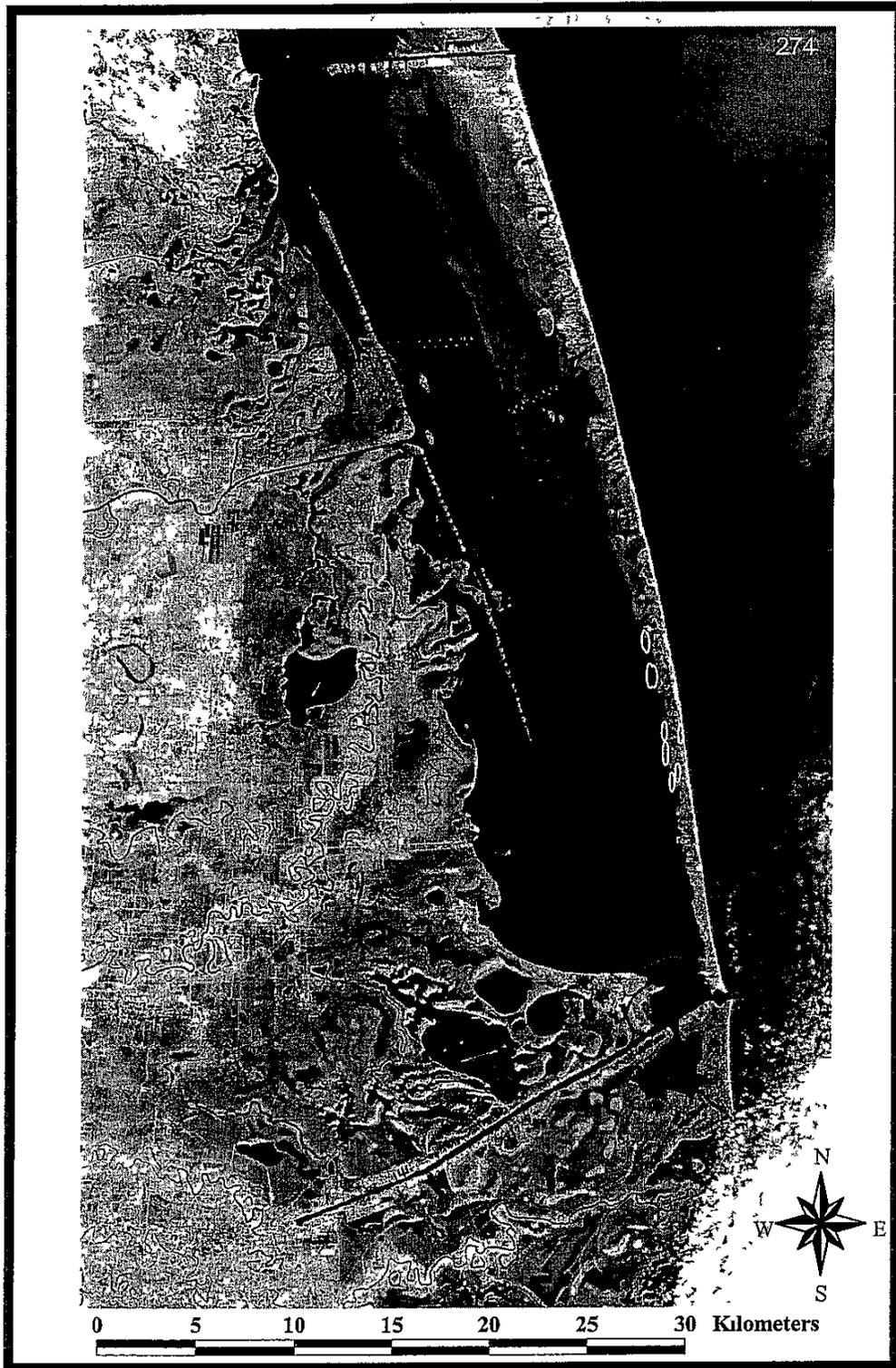


Figure 4a. Home range of Piping Plover #274



Figure 5a Home range of Piping Plover #301



Figure 6a Home range of Piping Plover #342



Figure 7a Home range of Piping Plover #417



Figure 8a. Home range of Piping Plover #440



Figure 9a. Home range of Piping Plover #461



Figure 10a. Home range of Piping Plover #479



Figure 11a Home range of Piping Plover #507



Figure 12a. Home range of Piping Plover #533



Figure 13a. Home range of Piping Plover #557

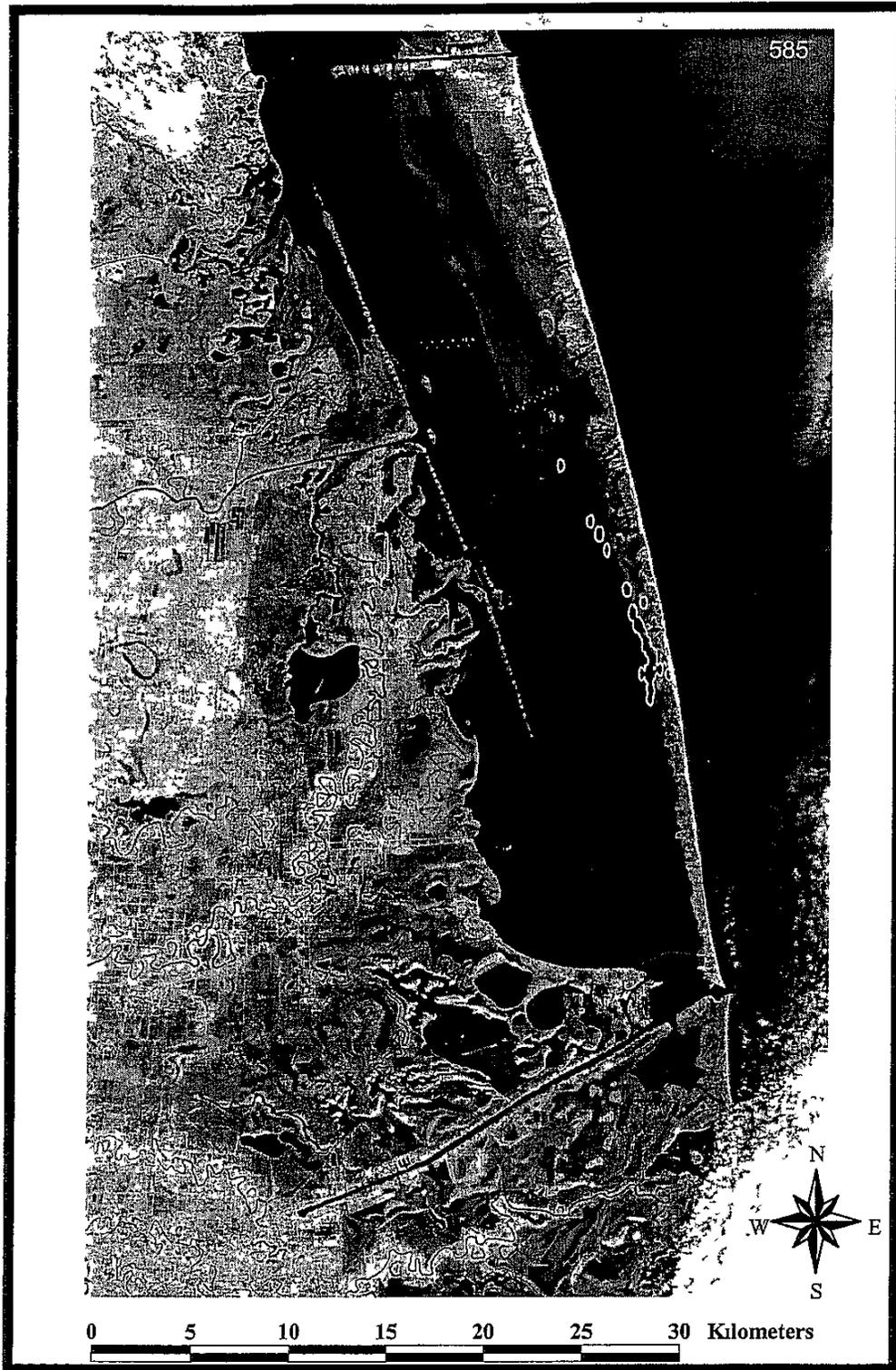


Figure 14a Home range of Piping Plover #585



Figure 15a Home range of Piping Plover #601



Figure 16a Home range of Piping Plover #612



Figure 17a. Home range of Piping Plover #621



Figure 18a Home range of Piping Plover #642

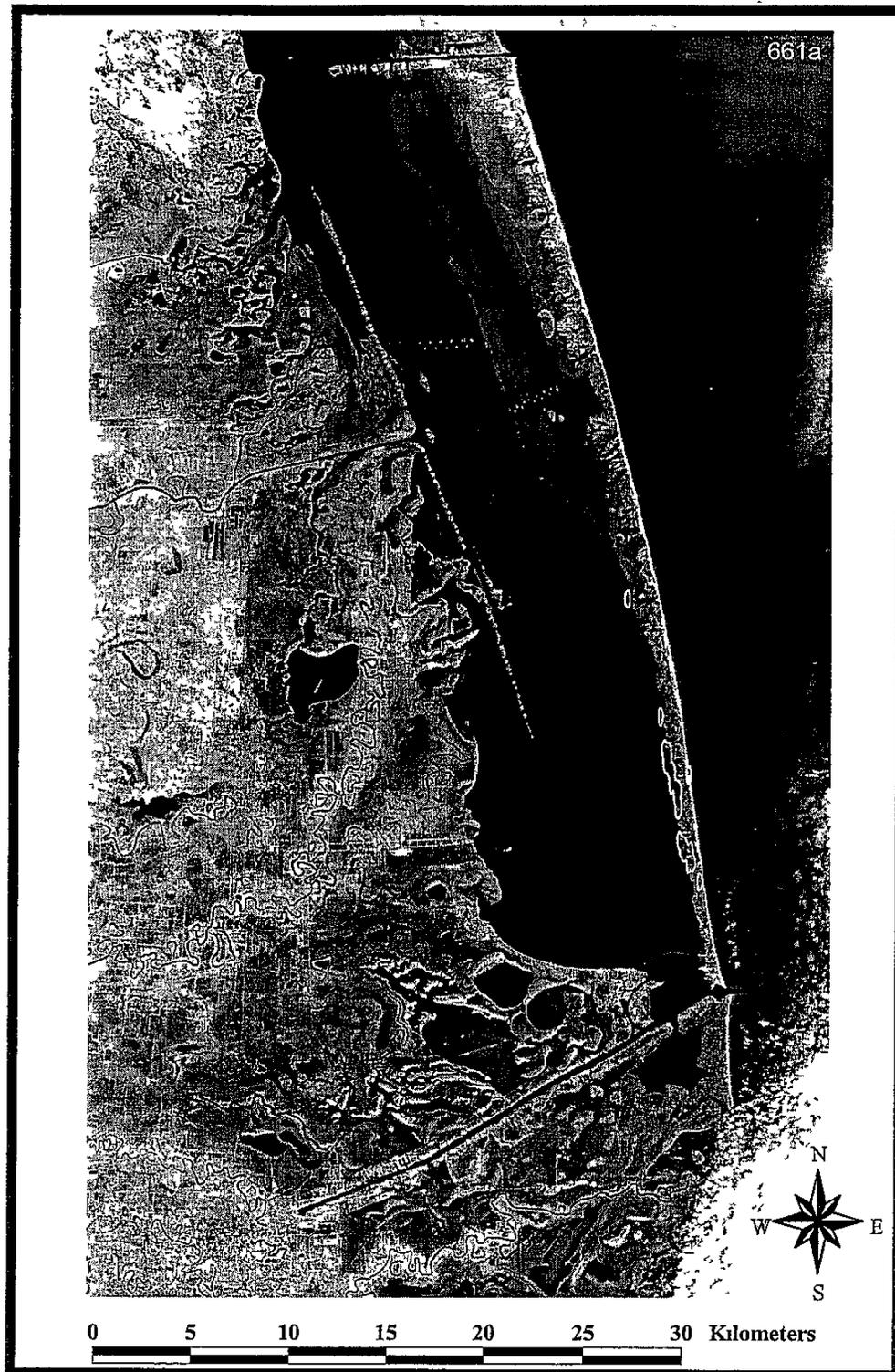


Figure 19a. Home range of Piping Plover #661a



Figure 20a Home range of Piping Plover #661b

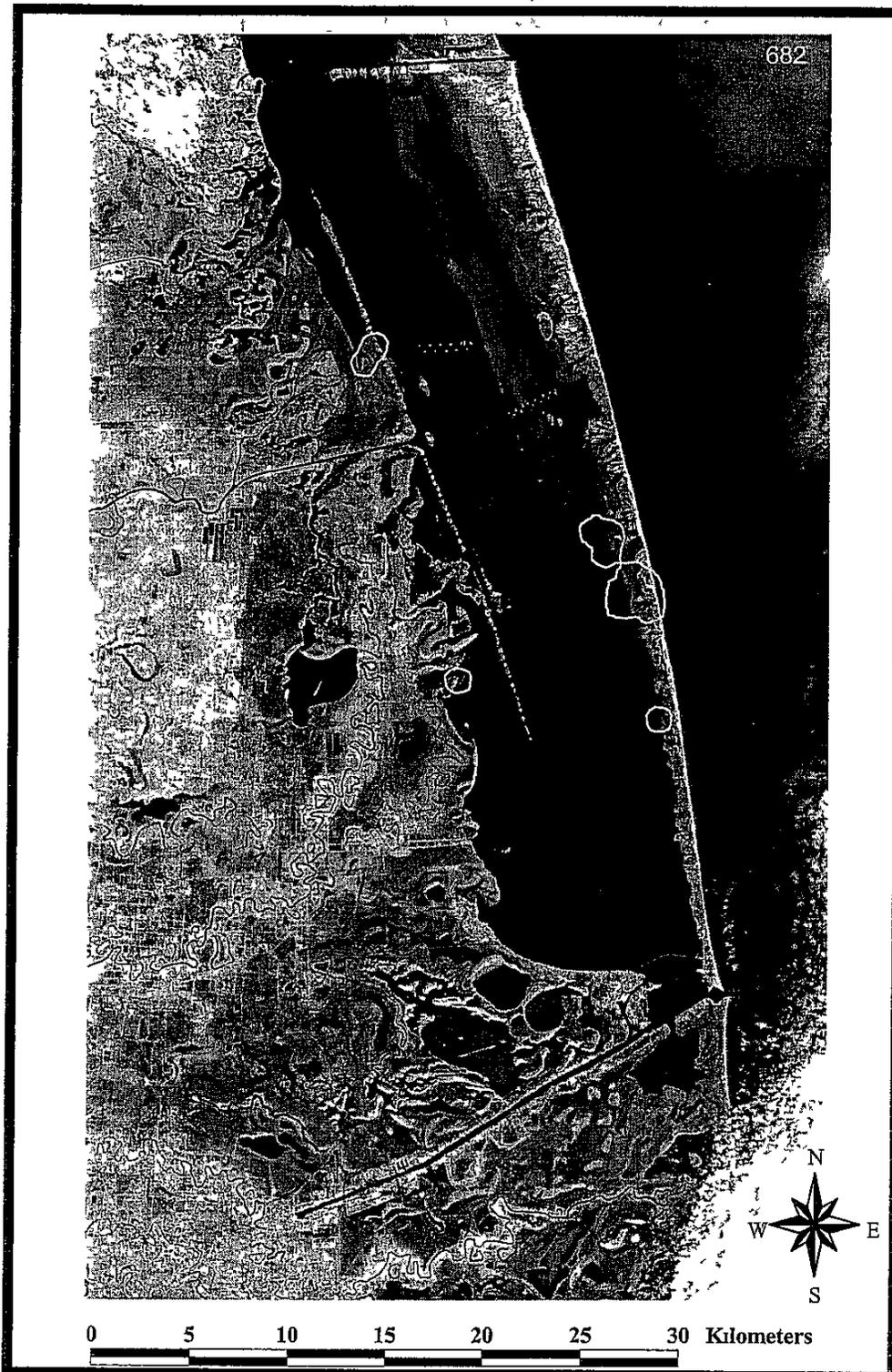


Figure 21a Home range of Piping Plover #682



Figure 22a. Home range of Piping Plover #701



Figure 23a Home range of Piping Plover #714



Figure 24a Home range of Piping Plover #720



Figure 25a Home range of Piping Plover #731



Figure 26a Home range of Piping Plover #741

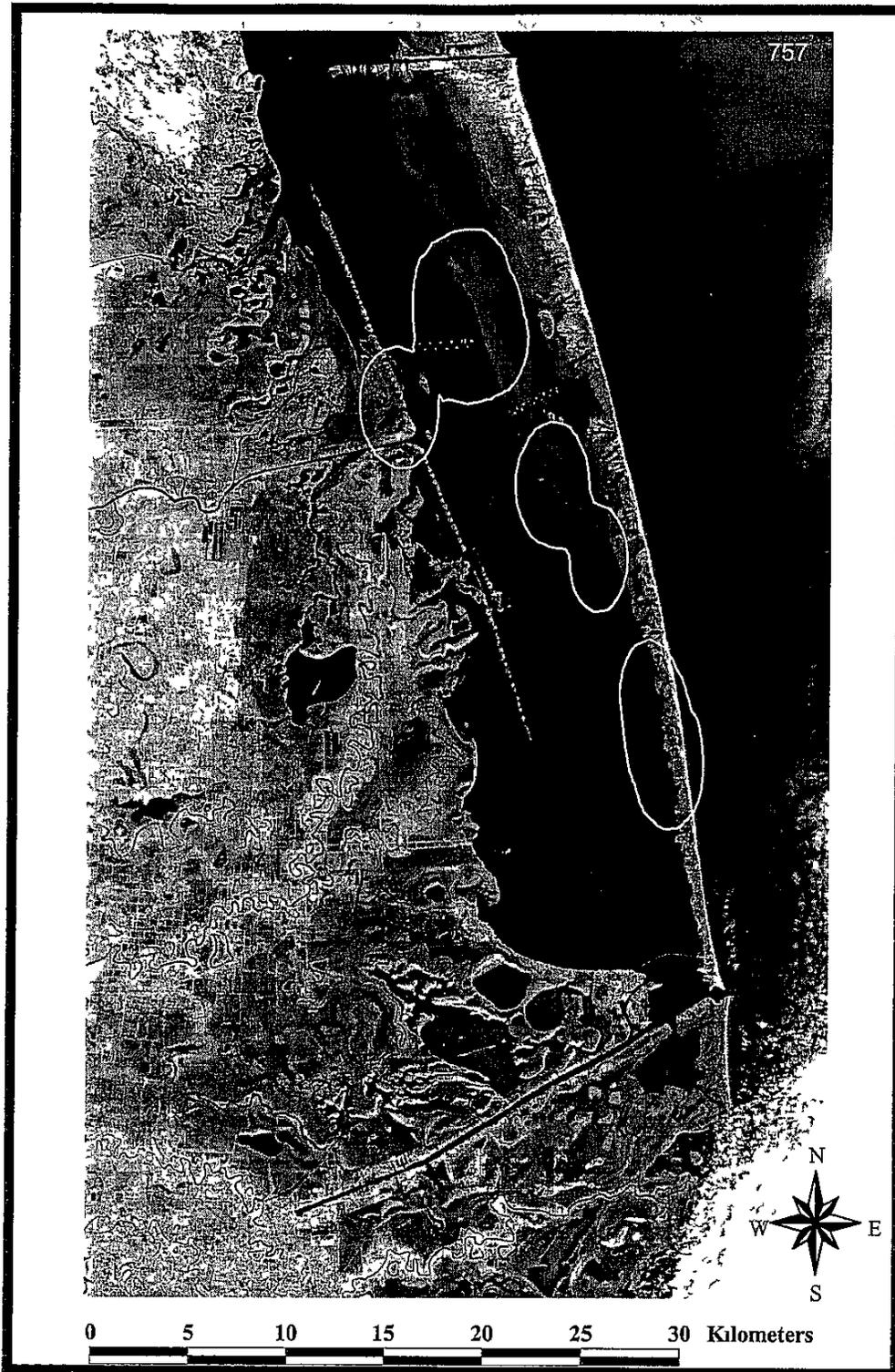


Figure 27a. Home range of Piping Plover #757

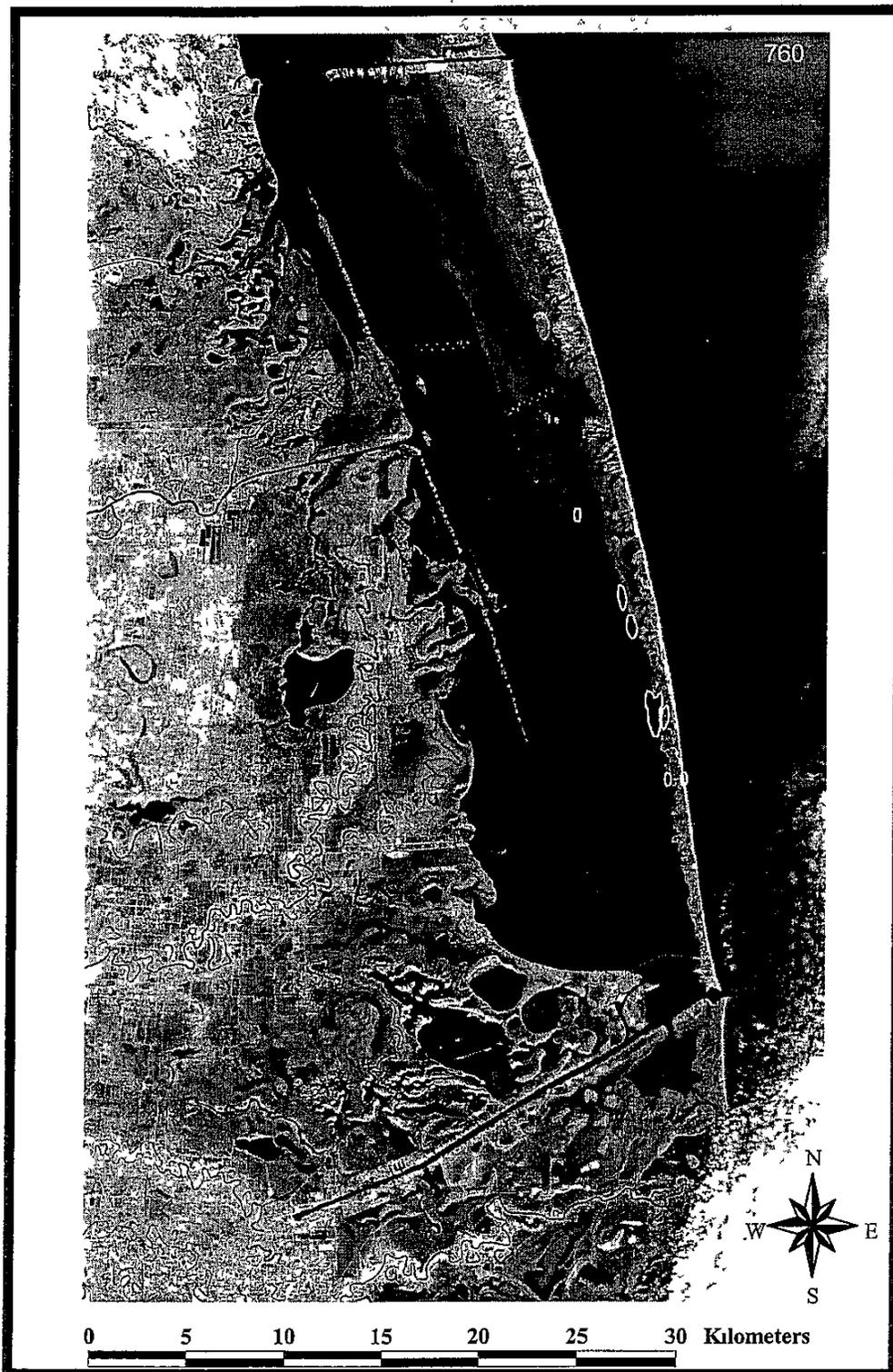


Figure 28a Home range of Piping Plover #760



Figure 29a Home range of Piping Plover #774



Figure 30a Home range of Piping Plover #778



Figure 31a Home range of Piping Plover #798



Figure 32a Home range of Piping Plover #801

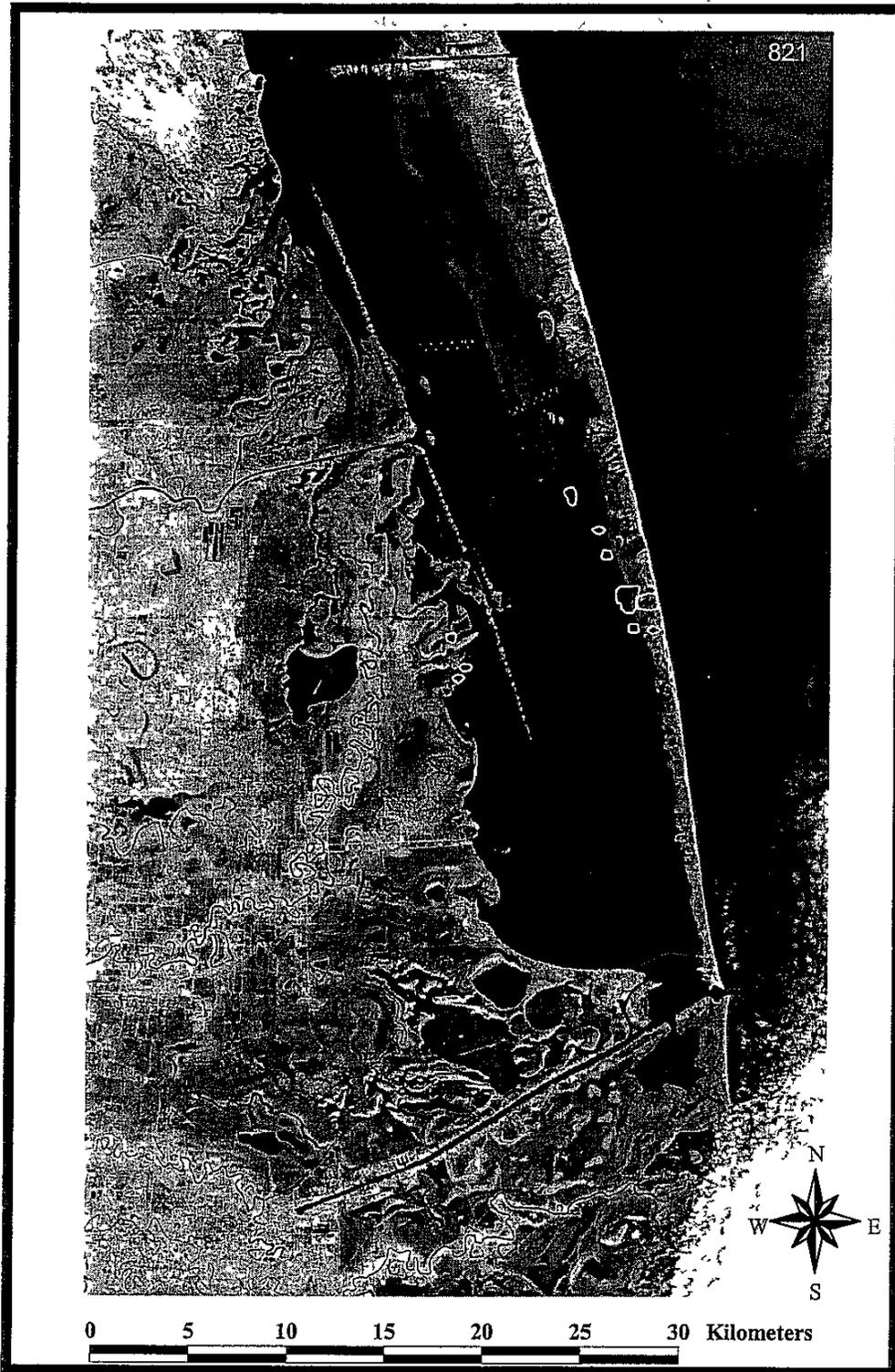


Figure 33a. Home range of Piping Plover #821

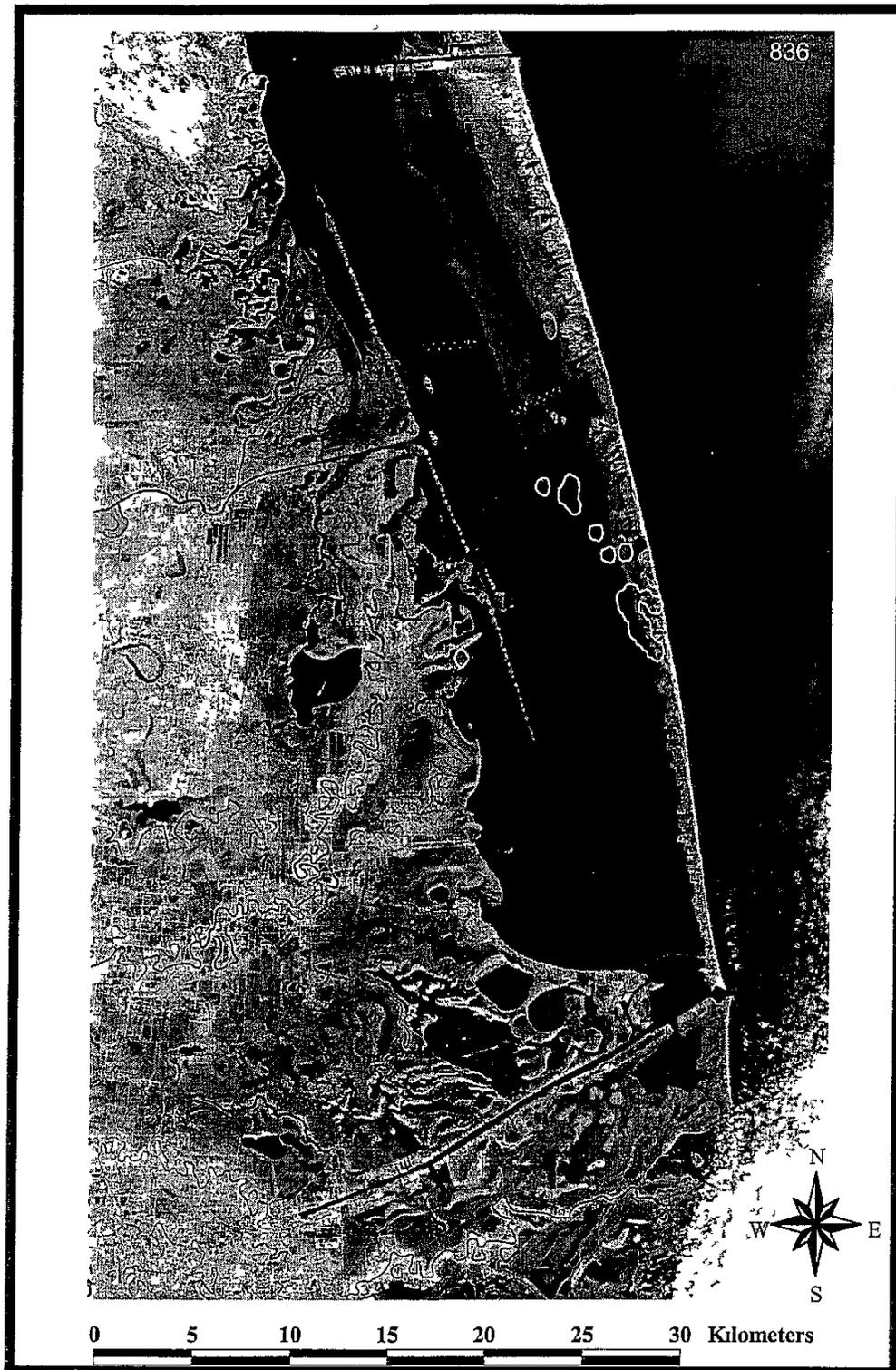


Figure 34a Home range of Piping Plover #836



Figure 35a. Home range of Piping Plover #842

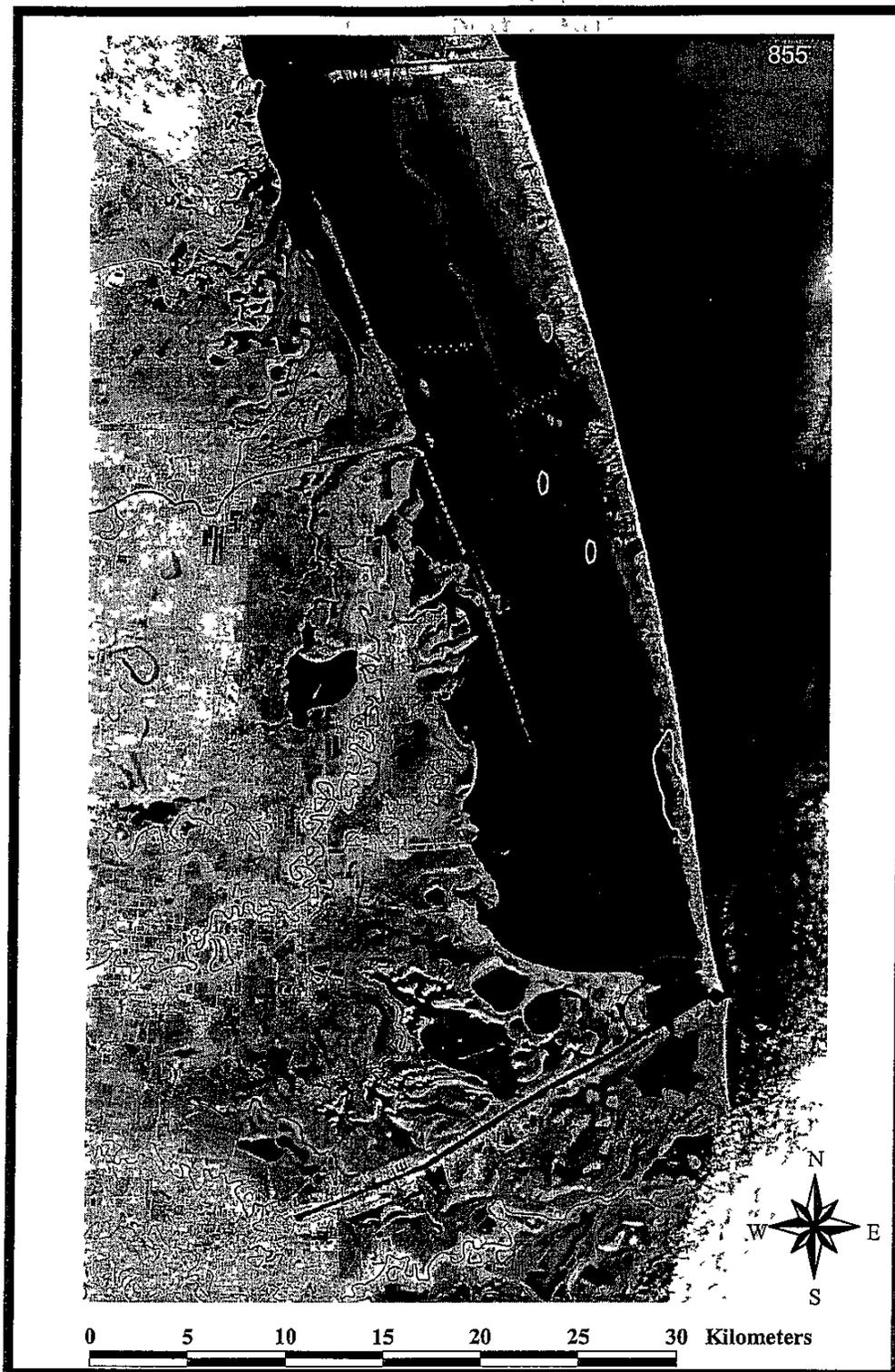


Figure 36a Home range of Piping Plover #855



Figure 37a Home range of Piping Plover #861



Figure 38a Home range of Piping Plover #871



Figure 39a. Home range of Piping Plover #882.



Figure 40a. Home range of Piping Plover #891.



Figure 41a. Home range of Piping Plover #901

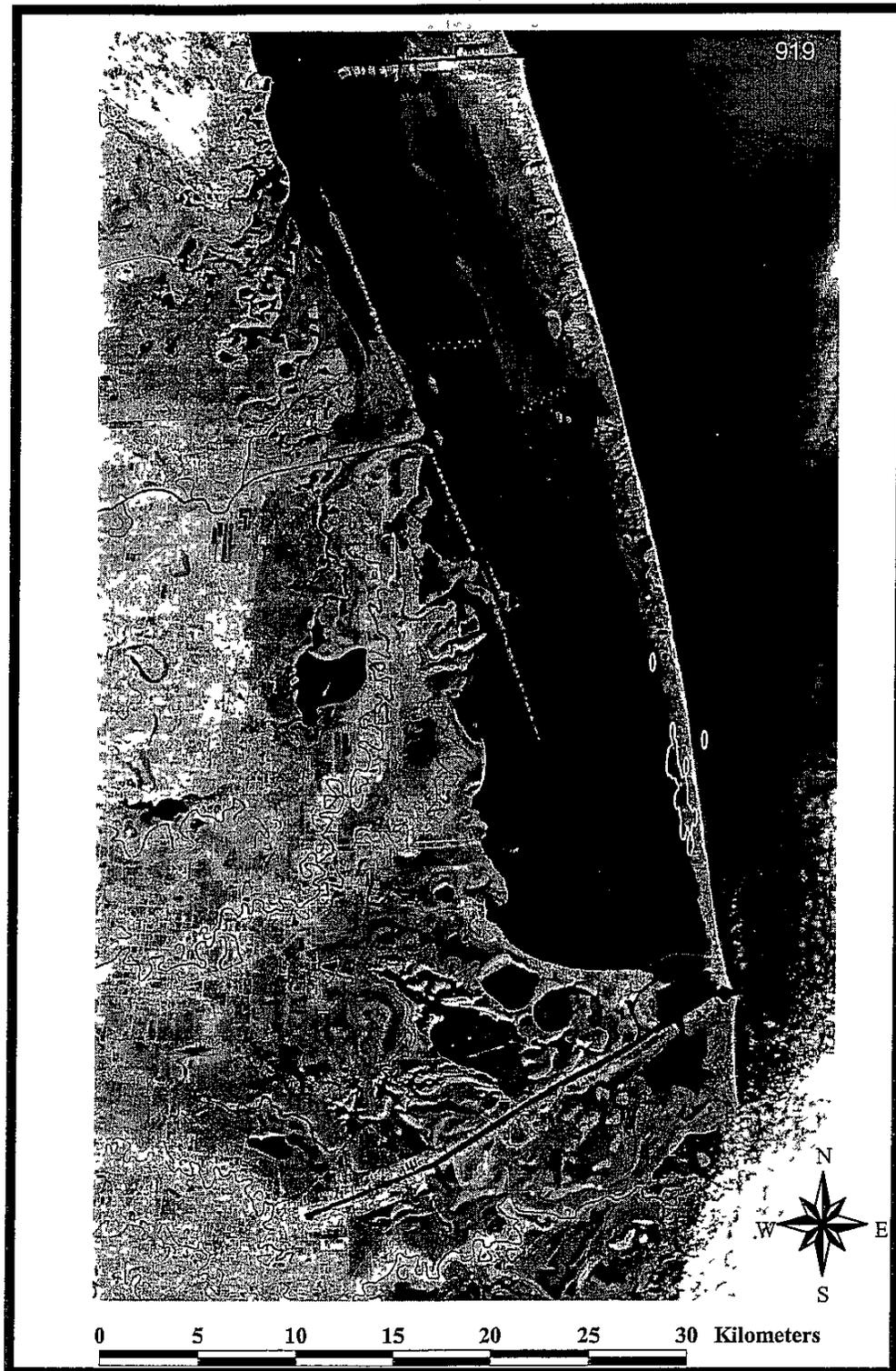


Figure 42a Home range of Piping Plover #919

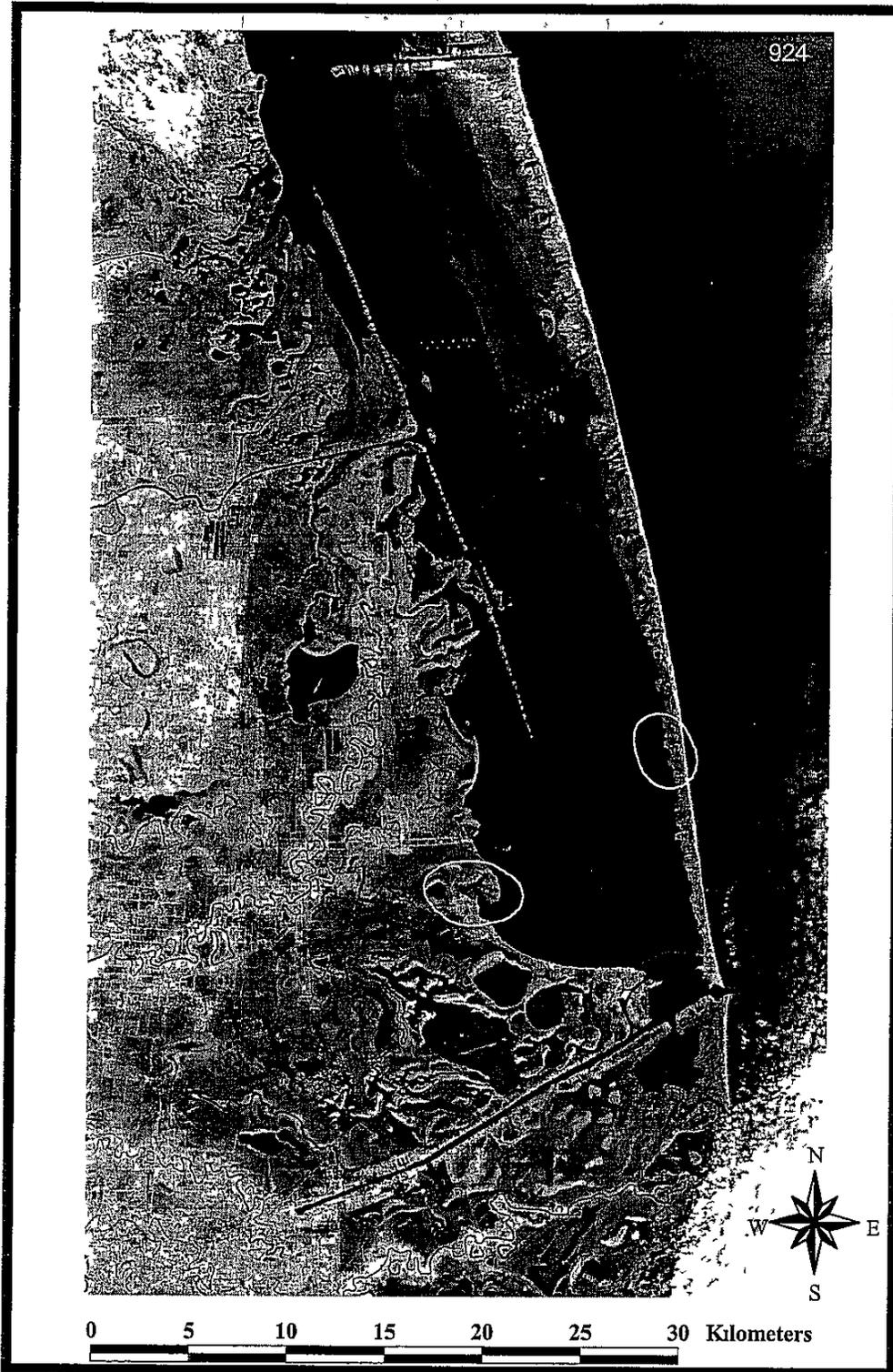


Figure 43a Home range of Piping Plover #924

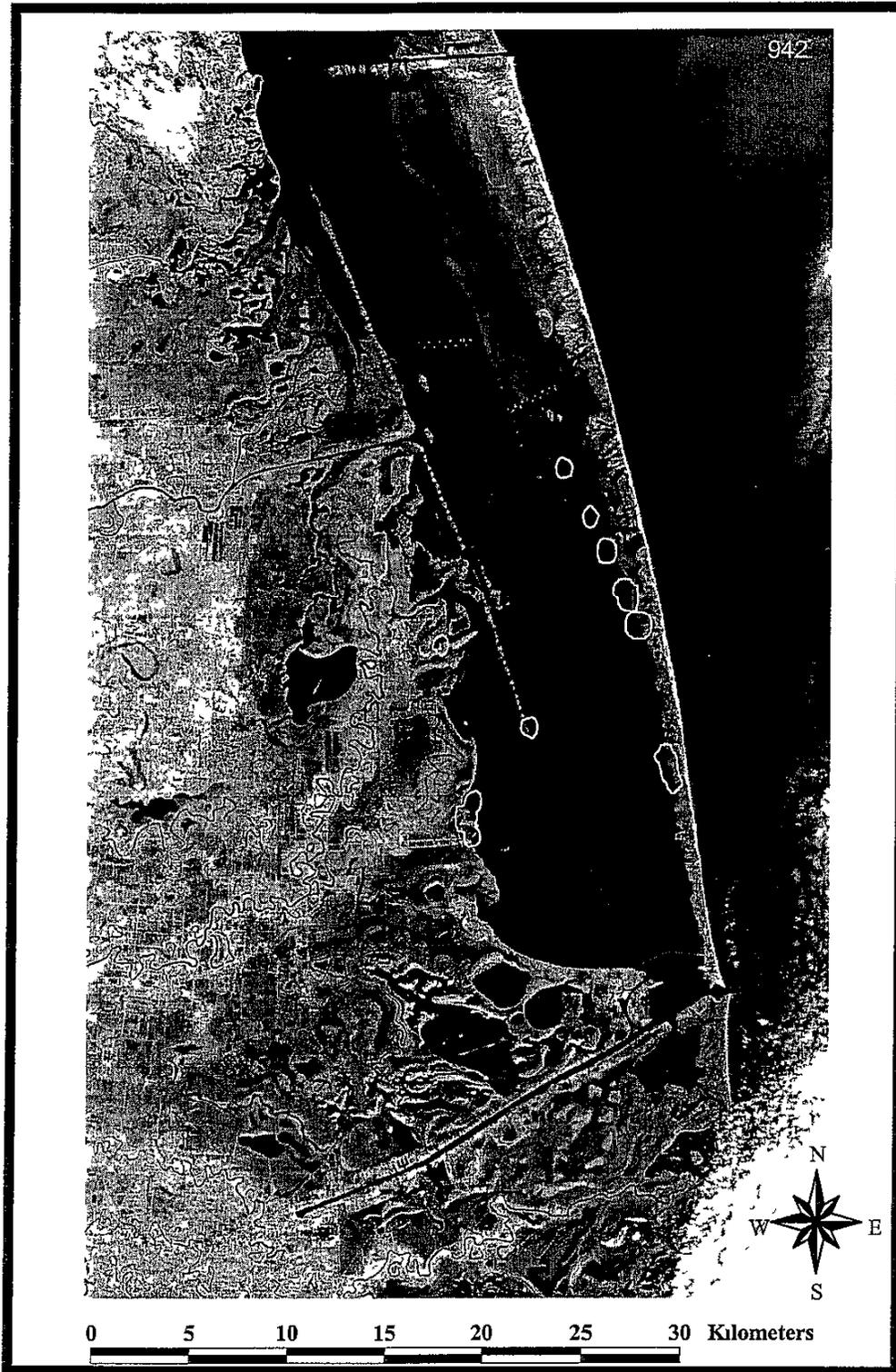


Figure 44a Home range of Piping Plover #942.

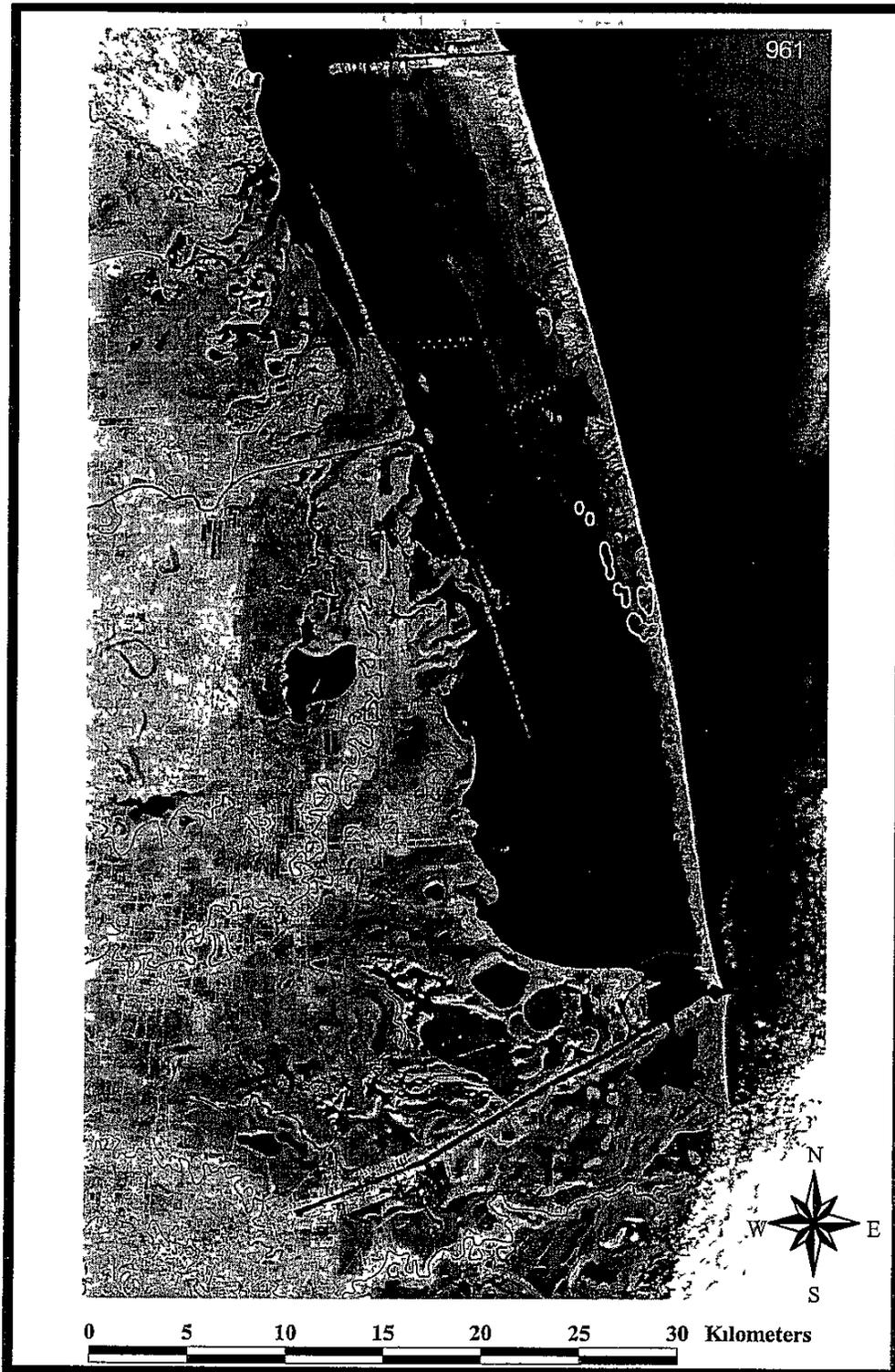


Figure 45a Home range of Piping Plover #961.



Figure 46a. Home range of Piping Plover #965



Figure 47a Home range of Piping Plover #981



Figure 48a Home range of Piping Plover #984

APPENDIX B.

Interannual site fidelity of Piping Plover to the southern Laguna Madre of Texas 1998-1999. Satellite image of the southern Laguna Madre with 1997-1998 polygons and 1998-1999 relocations overlaid. Polygons for 1997-1998 include radio and non-radio relocations (resightings of banded plovers after radio-transmitter battery failed), thus, 1997-1998 polygons differ from home range polygons within Appendix A.

†Note: Software programs that create polygons within linear habitats (i.e., tidal flats of barrier islands) can sometimes create contour lines that are slightly outside of the linear habitat (see Figure 33b, relocation on Gulf of Mexico shoreline). This is due to the algorithms used in creating the contours (E Seaman pers. com.). All relocation points were within the correct habitat and polygons still represent the appropriate area. Polygons encompassing GIWW areas are correct, as these birds were relocated when using dredged material placement islands and impoundments on mainland shores (i.e., See Figure 35b).



Figure 1b Interannual fidelity of Piping Plover # 50



Figure 2b Interannual fidelity of Piping Plover # 177



Figure 3b Interannual fidelity of Piping Plover # 219



Figure 4b. Interannual fidelity of Piping Plover # 248



Figure 5b Interannual fidelity of Piping Plover # 301



Figure 6b Interannual fidelity of Piping Plover # 342

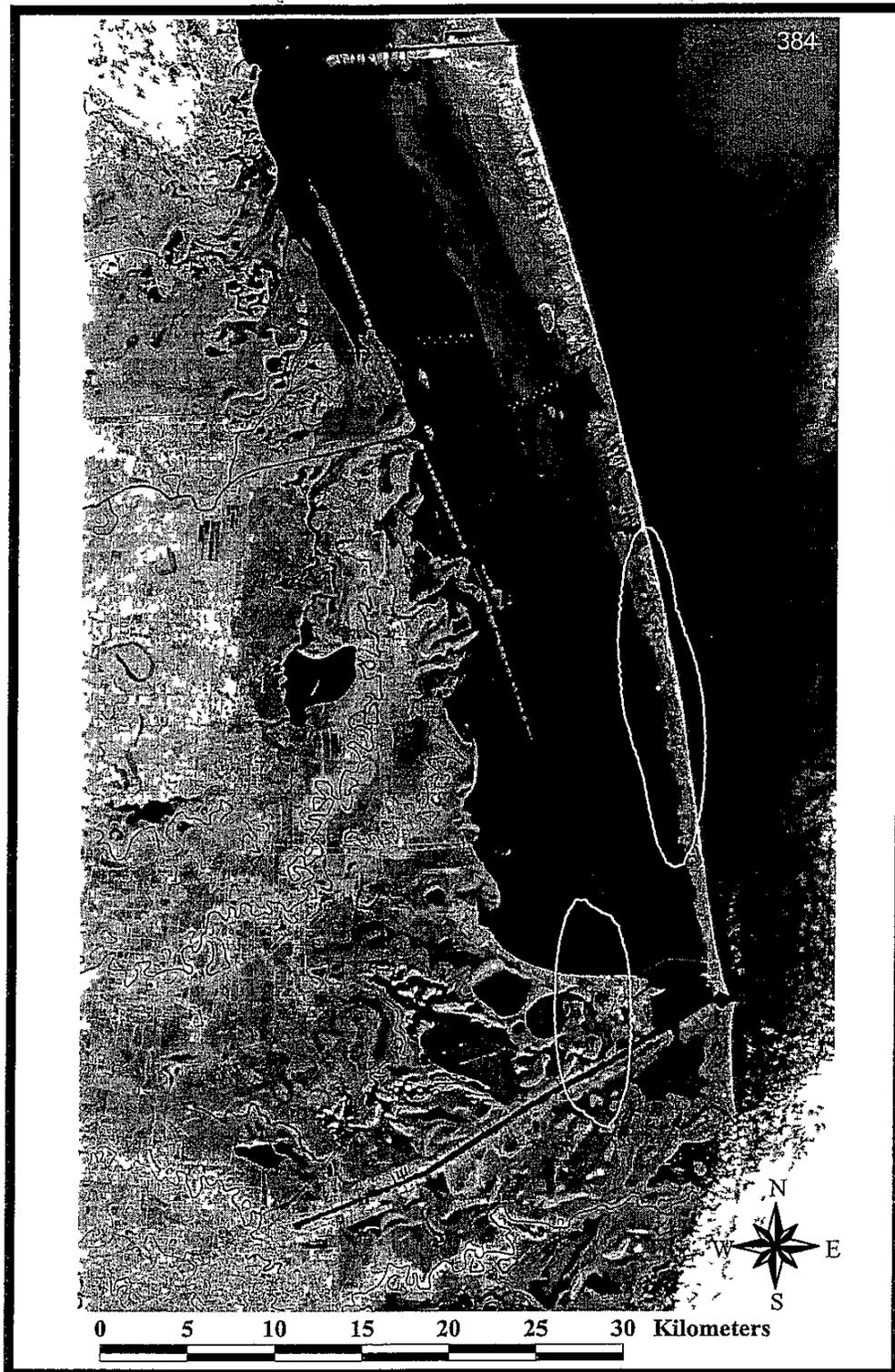


Figure 7b Interannual fidelity of Piping Plover # 384



Figure 8b Interannual fidelity of Piping Plover # 417



Figure 9b Interannual fidelity of Piping Plover # 440

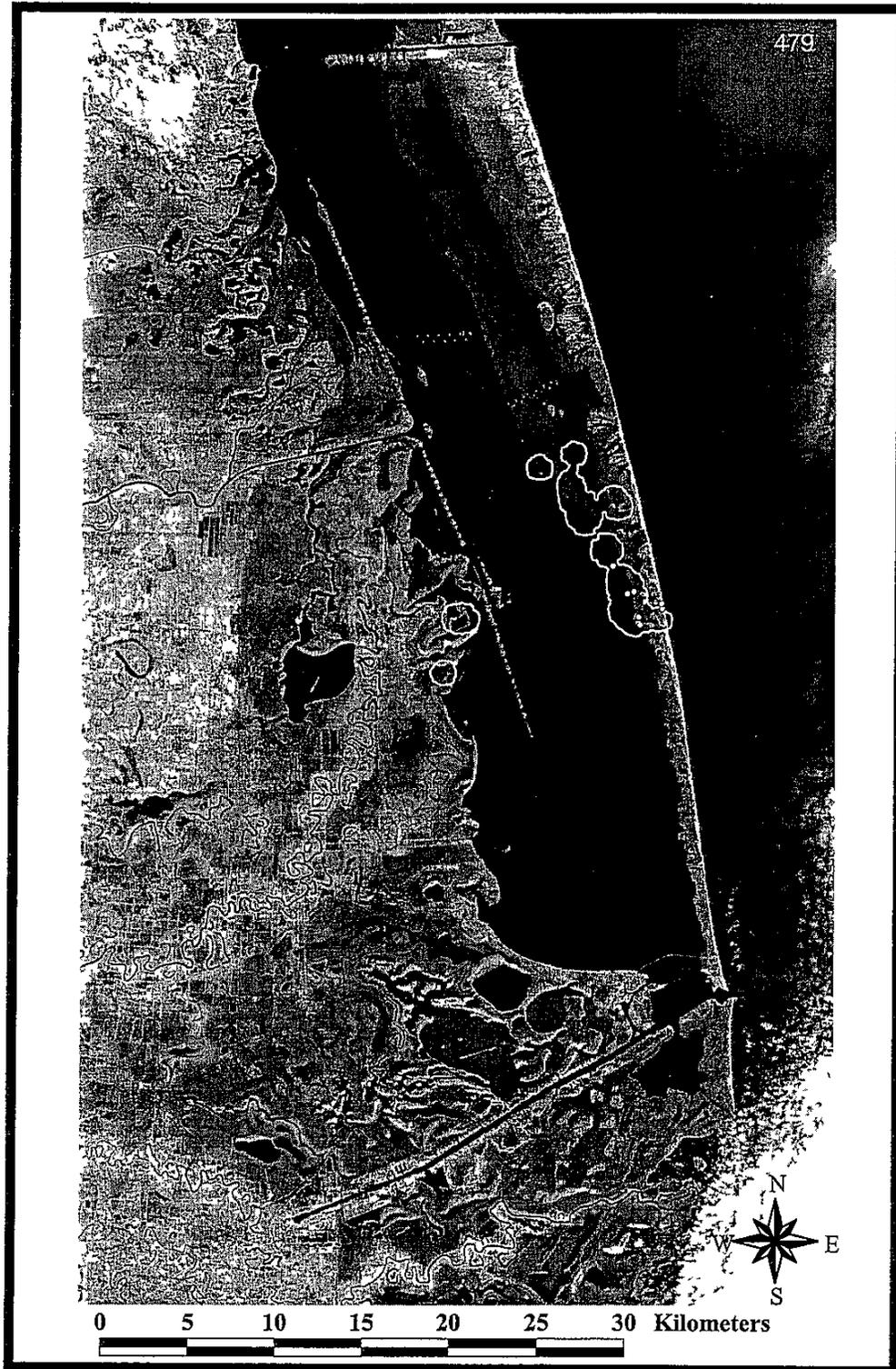


Figure 10b Interannual fidelity of Piping Plover # 479



Figure 11b Interannual fidelity of Piping Plover #507



Figure 12b Interannual fidelity of Piping Plover #533



Figure 13b Interannual fidelity of Piping Plover #585



Figure 14b Interannual fidelity of Piping Plover #612

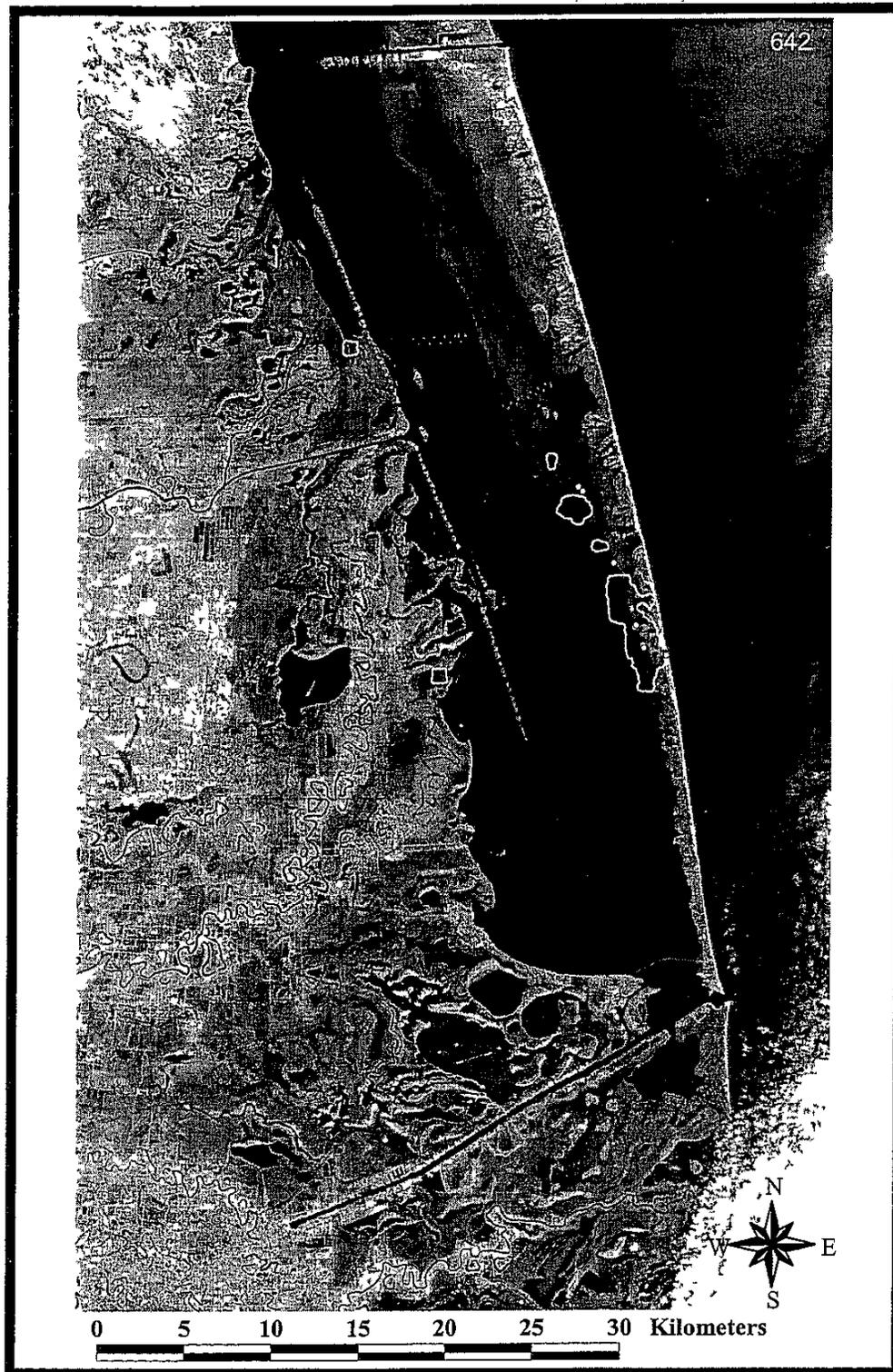


Figure 15b Interannual fidelity of Piping Plover #642



Figure 16b Interannual fidelity of Piping Plover #661a



Figure 17b. Interannual fidelity of Piping Plover #682



Figure 18b. Interannual fidelity of Piping Plover #701



Figure 19b. Interannual fidelity of Piping Plover #720



Figure 20b Interannual fidelity of Piping Plover #731



Figure 21b. Interannual fidelity of Piping Plover #757



Figure 22b Interannual fidelity of Piping Plover #760



Figure 23b Interannual fidelity of Piping Plover #778



Figure 24b Interannual fidelity of Piping Plover #798

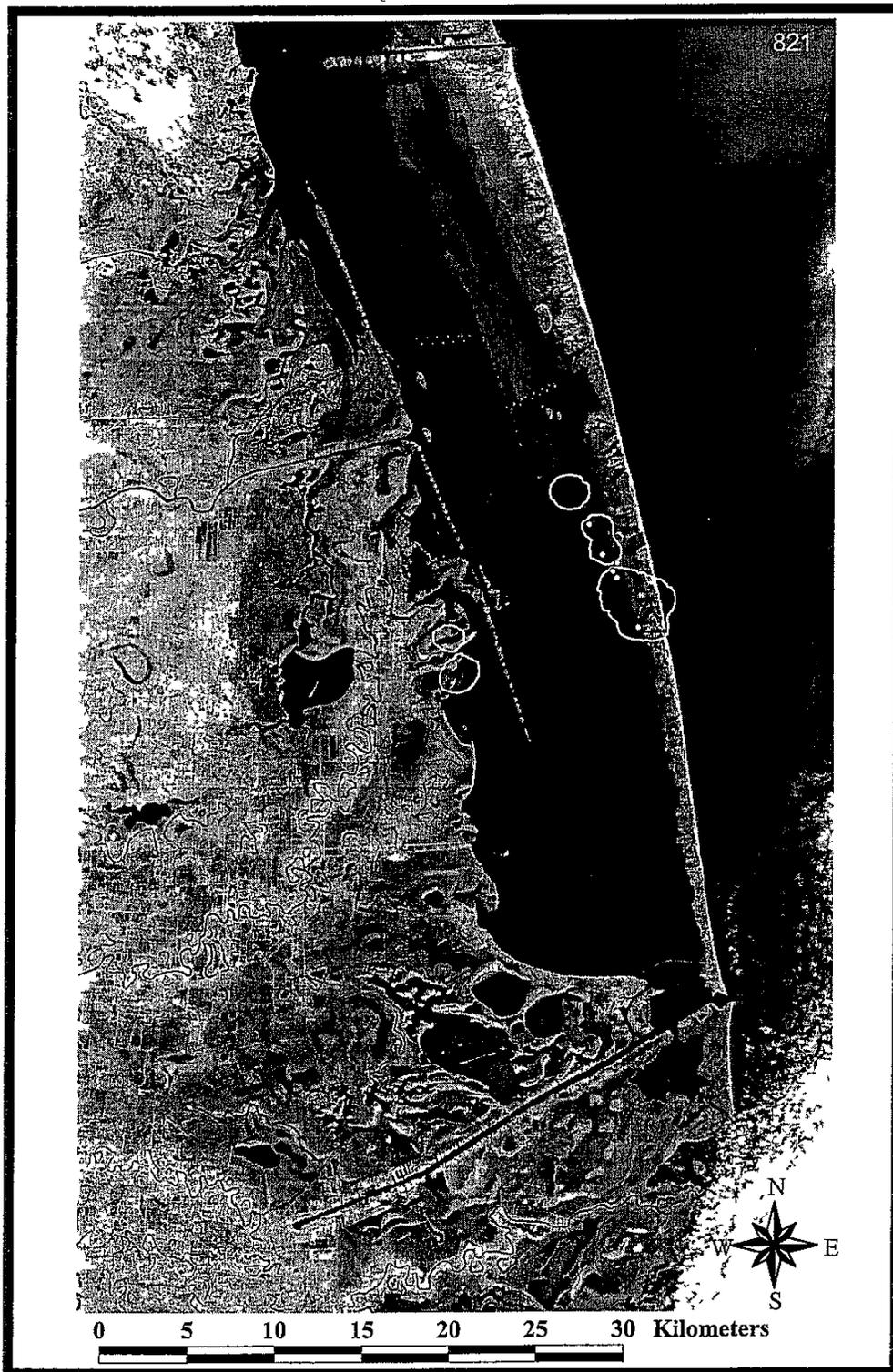


Figure 25b Interannual fidelity of Piping Plover #821



Figure 26b Interannual fidelity of Piping Plover #836



Figure 27b Interannual fidelity of Piping Plover #842



Figure 28b Interannual fidelity of Piping Plover #861



Figure 29b Interannual fidelity of Piping Plover #871



Figure 30b Interannual fidelity of Piping Plover #882.



Figure 31b Interannual fidelity of Piping Plover #891



Figure 32b Interannual fidelity of Piping Plover #901



Figure 33b Interannual fidelity of Piping Plover #919



Figure 34b. Interannual fidelity of Piping Plover #924



Figure 35b Interannual fidelity of Piping Plover #942



Figure 36b. Interannual fidelity of Piping Plover #961



Figure 37b. Interannual fidelity of Piping Plover #981



Figure 38b Interannual fidelity of Piping Plover #984



Figure 1c Relocations of Snowy Plover RW,W/US,W during 1997-1998 and 1998-1999 seasons



Figure 2c Relocations of Snowy Plover RW,W/US,Y during 1997-1998 and 1998-1999 seasons



Figure 3c. Relocations of Snowy Plover RW,Y/US,R during 1997-1998 and 1998-1999 seasons

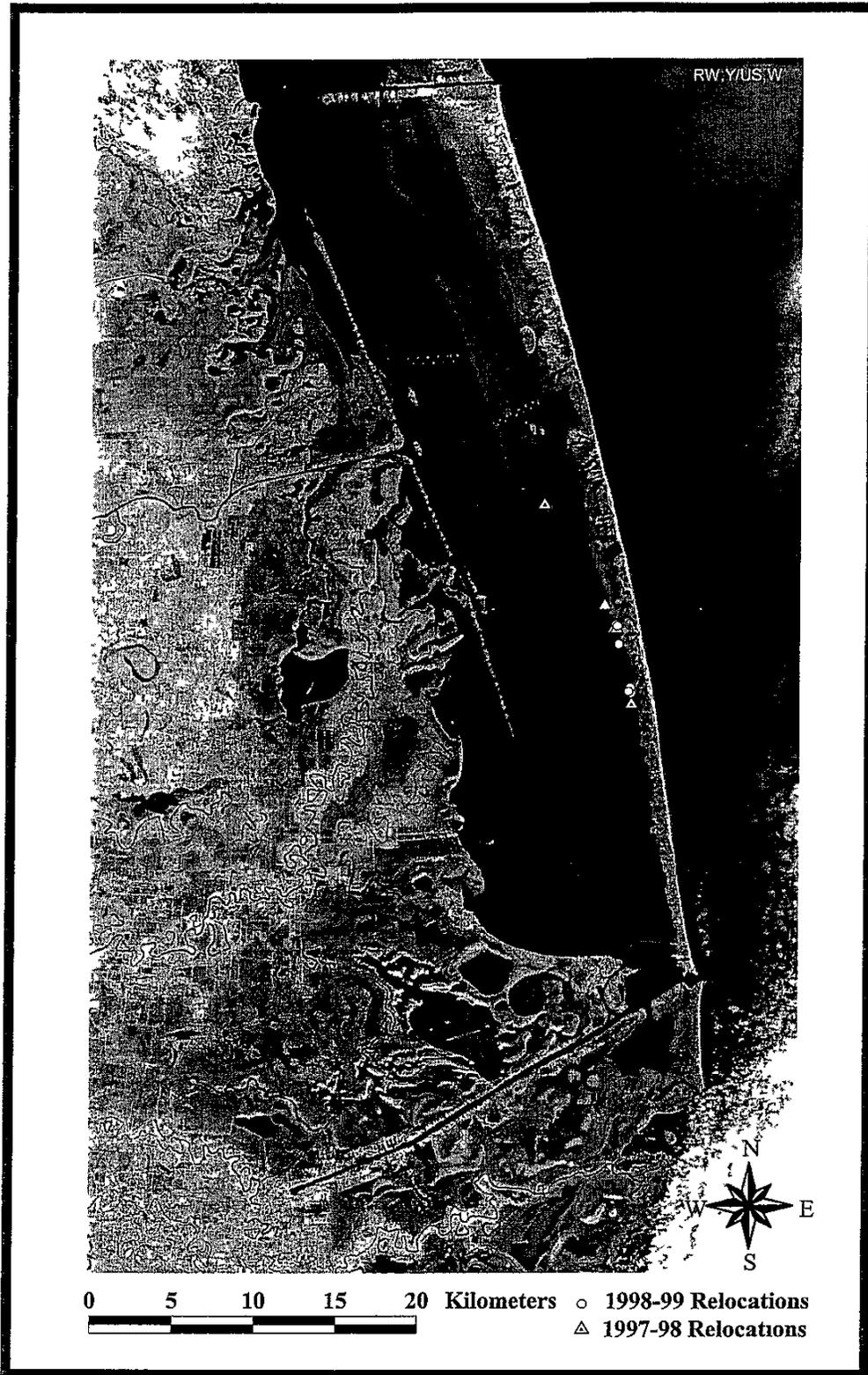


Figure 4c. Relocations of Snowy Plover RW,Y/US,W during 1997-1998 and 1998-1999 seasons



Figure 5c. Relocations of Snowy Plover R,Y/US,RW during 1997-1998 and 1998-1999 seasons



Figure 6c. Relocations of Snowy Plover Y,R/US,RW during 1997-1998 and 1998-1999 seasons



Figure 7c Relocations of Snowy Plover Y,RW/US,R during 1997-1998 and 1998-1999 seasons



Figure 8c Relocations of Snowy Plover Y,RW/US,W during 1997-1998 and 1998-1999 seasons



Figure 9c. Relocations of Snowy Plover Y,W/US,RW during 1997-1998 and 1998-1999 seasons



Figure 10c Relocations of Snowy Plover Y,Y/US,RW during 1997-1998 and 1998-1999 seasons



Figure 11c Relocations of Snowy Plover US, R/RW, R during 1997-1998 and 1998-1999 seasons



Figure 12c Relocations of Snowy Plover US, Y/RW, Y during 1997-1998 and 1998-1999 seasons



Figure 13c Relocations of Snowy Plover B,RW/US,B during 1997-1998 and 1998-1999 seasons



Figure 14c Relocations of Snowy Plover R,RW/US,Y during 1997-1998 and 1998-1999 seasons



Figure 15c Relocations of Snowy Plover RW, W/US, R during 1997-1998 and 1998-1999 seasons



Figure 16c Relocations of Snowy Plover RW,B/US,R during 1997-1998 and 1998-1999 seasons



Figure 17c Relocations of Snowy Plover RW,R/US,W during 1997-1998 and 1998-1999 seasons



Figure 18c Relocations of Snowy Plover RW, W/US, M during 1997-1998 and 1998-1999 seasons.



Figure 19c Relocations of Snowy Plover RW, W/US, B during 1997-1998 and 1998-1999 seasons