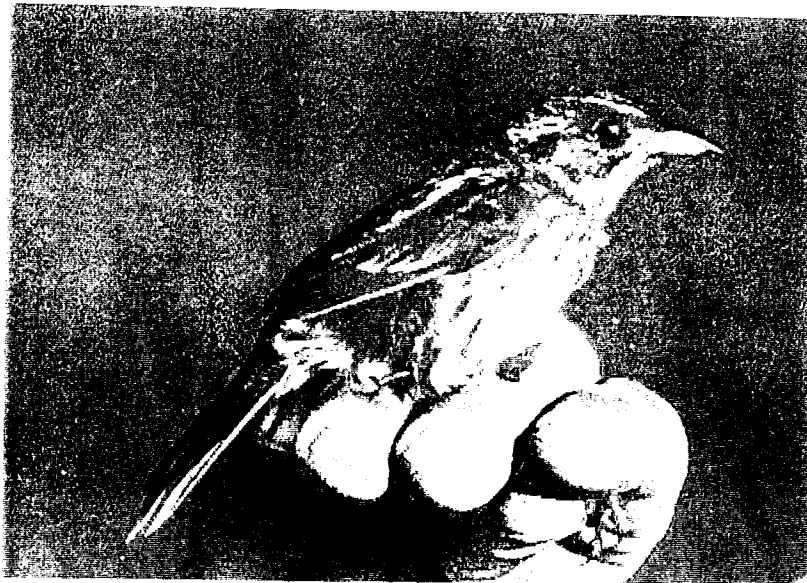


**NON-BREEDING SEASON ECOLOGY OF THE
CAPE SABLE SEASIDE SPARROW**
(Ammodramus maritimus mirabilis)

FINAL REPORT



Tylan F. Dean and Joan L. Morrison, Ph.D.

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EXECUTIVE SUMMARY

To date, the majority of the research on the endangered Cape Sable seaside sparrow has been conducted during the breeding season, when sparrows are visible, vocal, and easy to locate. However, to manage effectively for this sparrow it is essential to understand its habitat needs and behaviors throughout all aspects of its life history. During the non-breeding season (approximately June through February), Cape Sable seaside sparrows are secretive and difficult to locate consistently. We attached radio transmitters to 45 Cape Sable seaside sparrows during July 1997 – February 1998 and June 1998 – February 1999 for the purpose of documenting the movements, habitat use, and behaviors of these sparrows during the non-breeding season.

We evaluated the effects of transmitters on sparrows to ensure that there were no severe detrimental effects to the birds. None of the condition indicators we employed suggested that sparrows with transmitters declined in condition.

We radio-tracked 31 individual sparrows for extended periods (1-7 months), including both adults and juveniles. Our data indicate that juvenile sparrows travel widely following independence but adopt a sedentary movement pattern at the onset of molt. Subsequent to completing molt, all sparrows remain generally sedentary and maintain a non-breeding season home range that is larger than average breeding season home ranges. Individual sparrows were generally consistent in their scope and frequency of movements, and most birds moved on average 160 meters between consecutive locations (approximately 24 – 30 hours apart). Although many sparrows occasionally made longer (>500m) movements away from established home ranges, most returned to these previous home ranges. However, three individuals did not return to previous home ranges and settled in new home ranges 450, 6000, and 7000 meters away. Occasional movements even by only a few individuals among sparrow sub-populations are essential for maintaining genetic variability in the overall population. While our results indicate that sparrows are capable of moving long distances within the prairies, no sparrows used habitats other than the open muhly- and sawgrass-dominated prairies. We never recorded sparrows moving outside the prairies or through forested or other non-prairie habitats.

Micro-scale habitat selection models were not consistently able to distinguish between habitat characteristics at random points and at sparrow locations. However, when we compared the use by sparrows of micro-habitats under different hydrologic conditions, we found that selection of most habitat characteristics changed relative to the water depth at the site. Sparrows

used sites dominated by low vegetation (< 0.5 m in height) less frequently as water depths increased and used sawgrass-dominated sites and sawgrass clumps more frequently as water depth increased, suggesting the importance of structural variation in their overall habitat. Selection of other habitat characteristics also changed relative to water depth. Hydrologic condition of the prairies is one of the most variable environmental characteristics of this ecosystem. Interpolated topographies of our two study sites indicated that there is as much as 20-30 cm of topographic variation within areas as small as 1 km^2 . Water levels varied dramatically over time at our study sites, and the small-scale variation in elevation that we recorded undoubtedly translates into the differences in vegetative structural characteristics that may help buffer sparrows from extreme hydrologic conditions.

Surveys conducted in the prairies provided evidence that sparrows do not dramatically change distribution or habitat use between the breeding and the non-breeding seasons. Comparisons of sparrow occurrence during the non-breeding season on breeding season study plots and at helicopter survey sites revealed no substantial changes in sparrow distribution between these seasons.

We documented 5 sparrow mortalities during our two study periods, mostly due to predation, and many radio-marked sparrows disappeared, predominantly due to transmitter failure. While our estimated weekly survival rates varied considerably between the 2 years, they compare favorably with other published survival rates for Cape Sable seaside sparrows, which suggest an annual survival rate > 0.50 .

We documented sparrows breeding in August in both years, which is much later than has previously been recognized. We documented a decline in detections of unmarked sparrows beginning in late October and continuing through December as other authors have noted. However, we determined that this change merely represents a behavioral change, and sparrows do not change their movement patterns, distribution, or habitat use between the breeding and the non-breeding seasons.

Limited information on sparrow diet during the non-breeding season obtained from fecal samples suggests that this bird remains insectivorous year round and relies little on seeds. Genetic analyses of mitochondrial DNA showed that the Cape Sable seaside sparrow's matrilineal heritage is clearly from the Atlantic clade of seaside sparrows. We documented

consistent, moderate infestations of chewing lice and a few feather mites on sparrows. We recorded no evidence of hemoparasitism or other disease, from a limited set of blood samples.

Our results indicate several factors important to consider in management and recovery planning for the Cape Sable seaside sparrow:

- 1) The protracted breeding season, potentially into August each year, which is probably dependent on the timing and intensity of water level change in the prairies;
- 2) The general sedentary nature of the subspecies. While Cape Sable seaside sparrows do have the capability of traveling relatively long distances (> 2km) they are generally sedentary animals and remain strongly tied to the marl prairies. This information has strong implications with regards to (1) maintaining quantity and spatial arrangements of suitable habitats and (2) maintaining genetic variability within the subspecies.
- 3) The finding that selection of micro-habitat characteristics by sparrows changes over time in response to changing hydrologic conditions. Our results suggest that maintaining suitable structural variation at a small scale within the prairies may be just as important as maintaining overall suitable vegetation composition.
- 4) The distribution of Cape Sable seaside sparrows across the southern Everglades does not change dramatically between the breeding and non-breeding seasons. This subspecies is clearly strongly tied to the marl prairies and is sedentary in nature; clearly they have evolved the ability to tolerate the variation in environmental conditions inherent in this ecosystem while remaining there. This finding may have important implications for the timing and scope of management activities such as fire and management of water levels.

INTRODUCTION

The Cape Sable seaside sparrow (*Ammodramus maritimus mirabilis*) is one of nine formally recognized subspecies in the United States, 8 of which are extant. This sparrow was initially considered a distinct species but was relegated to sub-specific status in the early 1970's (Eisenmann 1973). This sparrow is endemic to the Everglades system of South Florida and diverges from other subspecies of seaside sparrows by inhabiting freshwater marshes and seasonally inundated freshwater marl prairies (Kushlan and Bass 1983).

The Cape Sable seaside sparrow was listed as endangered by the U.S. Fish and Wildlife Service and the Florida Fish and Wildlife Conservation Commission in 1973 and has had a complicated history of population disappearance, fluctuation, recovery, and rediscovery (USFWS 1981). The originally described population occupied the brackish-water cordgrass (*Spartina bakeri*) marshes of Cape Sable (Kushlan and Bass 1983, Werner and Woolfenden 1983), but this population went extinct subsequent to changes to the vegetation following a hurricane in 1936 (Stimson 1956). The subspecies was subsequently rediscovered in the fresh water marshes within the core of the Everglades system. Since that rediscovery, scientists have recorded the disappearance of seemingly large populations (> 400 birds) such as the one within Taylor Slough (Kushlan and Bass 1983), while small populations have increased substantially in size. Currently, the Cape Sable seaside sparrow exists in a series of six disjunct populations separated by areas of unsuitable habitat (Lockwood et al. 1997, 1999a). Drainage, development, and modified water flow have affected the Everglades system within the past 50 years (Robertson and Frederick 1994) and have been implicated in some of the observed changes in Cape Sable seaside sparrow populations (Nott et al. 1998, Curnutt et al. 1998).

To date, nearly all of the research and information available on Cape Sable seaside sparrows has resulted from studies and observations conducted during the sparrow's breeding-season, while all aspects of the sparrow's non-breeding season ecology have remained poorly known. The primary reason for the lack of non-breeding season research is the sparrow's extremely secretive nature during certain parts of the year (Werner and Woolfenden 1983, Balent et al. 1997). This secretiveness makes it difficult or impossible to study the sparrow's behavior through direct observation. While breeding season study allows evaluation of population size, demography, and reproductive ecology, it does not allow full evaluation of habitat use, movement patterns and capability, survival, or other critical aspects of this sparrow's ecology

and life history that occur during the non-breeding season. To manage effectively for the persistence or recovery of this endangered sparrow, knowledge of its ecology and life history during all portions of the year is required.

We studied the non-breeding season ecology of the Cape Sable seaside sparrow in Everglades National Park during two non-breeding seasons, July 1997 – February 1998 and June 1998 – February 1999. We attached small radio transmitters to Cape Sable seaside sparrows during these periods so we could consistently locate sparrows to record their habitat use, movements, condition, survival, and behaviors. Through regular location of radio marked sparrows over extended periods, we have learned much about this sparrow's ecology during the non-breeding season.

OBJECTIVES

The primary objectives of this study were to:

- 1) quantify the frequency and scope of movements made by Cape Sable seaside sparrows during the non-breeding season;
- 2) evaluate the effects of radio transmitters on the sparrows;
- 3) determine non-breeding season habitat associations:
 - a) determine landscape-level associations;
 - b) evaluate micro-site habitat selection;
 - c) determine patterns of habitat use relative to hydrologic conditions;
- 4) estimate survival rates for Cape Sable seaside sparrows during the non-breeding season:
 - a) identify mortality factors;
 - b) identify potential health issues (parasites, disease);
- 5) assess distribution of sparrows across the landscape relative to breeding season distributions.

Secondary objectives were to:

- 1) document patterns of behavior and interactions;
- 2) investigate genetic relationships with other subspecies of seaside sparrows.
- 3) obtain additional information, as feasible, on diet, parasites, and disease.

STUDY AREAS

We conducted this project within the muhly (*Muhlenbergia filipes*) prairies that support the Ingraham Highway population of sparrows (Population B, referred to in Lockwood et al. 1999a). The landscape is primarily composed of large expanses of open prairies with varying amounts of the dominant graminoid species, which include muhly, sawgrass (*Cladium jamaicense*), south Florida bluestem (*Schizocyrium rhizomatum*), black-topped sedge (*Schoenus nigricans*), and several species of beak rushes (*Rhynchospora* spp.). Many other species of plants occur within these prairies (Lockwood et al. 1999b, Olmstead and Armentano 1997), but these graminoids generally make up 70-95% of the vegetation cover (see below). These prairies are interspersed with tree islands, tropical hardwood hammocks, and cypress domes and also contain areas of dwarf cypress (*Taxodia* spp.) forest and pine-hardwood forests. The Ingraham Highway sparrow population exists within the prairies bordered on the north by Pine Island, on the east by Taylor Slough, on the south by the mangrove belt that borders Florida Bay, and on the west by Shark River Slough (Figure 1).

We established two primary study sites within this large area, in which we captured and radio-marked sparrows (Figure 1). These sites, separated by approximately 2 km of prairie were located in the area of contiguous muhly prairie immediately north of Old Ingraham Highway (Figure 1). The Half Raccoon site (HR) was located immediately east of the Far East breeding season study plot (Lockwood et al. 1999a), while the End of Ingraham site (EI) was northwest of the current end of Old Ingraham Highway, due west of the North Ingraham breeding season study plot and directly north of the Ingraham South breeding season study plot (Lockwood et al. 1999a). Each site was approximately 1 km² in size.

While these two non-breeding season study sites served as the focal areas for capturing and radio-marking sparrows, the extent of our activities was also dictated by movements of the sparrows. Once we attached radio transmitters, we followed sparrows wherever they traveled and continued to track their movements whenever possible for the full duration of the study period each year.

We established additional areas away from the primary study sites in which we conducted habitat measurements and documented the presence or absence of sparrows during the non-breeding season (Figure 2). During the first field season (1997-1998), we established survey transects at 11 sites; 10 were within the general area of Population B, and one was in the prairies

of Taylor Slough. Several of these sites were within the Ingraham North, Ingraham South, Far East, Alligator Hammock, North Mahogany, and Dogleg breeding season study plots (Lockwood et al. 1999a). We identified two other sites including one in the southeastern portion of the general Ingraham Highway area (Far South), and the other just northeast of Mahogany Hammock (Mahogany).

During the second field season, we established 34 circular plots for the purposes of assessing sparrow non-breeding distributions. These plots coincided with breeding season helicopter survey point-count locations within the Ingraham Highway population of sparrows (Figure 2). We used published point count location coordinates as the center points for these circular plots (see below).

METHODS

Trapping and banding

Because sparrows are secretive during the non-breeding season, we employed a mist-netting technique in which we located an individual sparrow and then deployed mist nets with the objective of capturing that specific individual. To locate sparrows for capture, we searched within our primary study sites using both visual and aural cues. In addition, we sometimes dragged weighted ropes between observers to flush sparrows from the low vegetation (Fletcher et al. 2000). When we located a sparrow, we placed two to three 12-meter mist nets near (within 50 m) the sparrow's location, and 2-5 observers worked to flush the bird into the net.

Once we captured a sparrow, we recorded basic morphological characteristics including mass, wing chord, sex, age, molt progression, and fat score (a visual estimate of the quantity of visible sub-dermal fat). All sparrows that we captured received a unique combination of colored leg bands. All sparrows from our study received a purple plastic colored band on the same leg as the uniquely numbered aluminum U.S. Fish & Wildlife Service band, and a combination of two colored plastic bands on the other leg. The purple band used in conjunction with the aluminum band has not been used by other researchers banding these sparrows and served to identify sparrows banded only by our research team. These unique color band combinations enabled us to identify individuals if we subsequently observed them. Unbanded sparrows were evaluated for transmitter attachment (see below). If we captured a sparrow that had been banded by other

researchers, we recorded its morphological characteristics and released it without attaching a transmitter.

Transmitter attachment

If captured sparrows appeared to be in good health (weighed > 17.0 g, had well-developed breast muscle, and no signs of physical injury), we attached a radio transmitter using a modified leg-loop harness (Rappole and Tipton 1991) constructed from braided nylon fishing line. Transmitters weighed 1.0-1.2 g (Advanced Telemetry Systems, Inc. small bird transmitters) and had a battery life of 50-70 days. We used braided nylon for harnesses because of its non-abrasive nature and slight elasticity. We also inserted a 0.5 cm length of cotton-polyester blend carpet thread into each harness to provide a "weak link" that would allow the transmitter to drop off the sparrow in the event that we were unable to recapture it and remove the transmitter. Transmitter harnesses were fitted to each individual sparrow and tied off with knots secured with super-glue. The transmitter was also glued to the harness to prevent the transmitter from moving down the side of the sparrow's leg. This attachment technique loosely held the transmitter on the sparrow's lower back, over the synsacrum, with the antenna extending over the top of the tail.

After transmitter attachment, we briefly placed each sparrow into a test cage (52 x 40 x 20 cm) and monitored its activity for 1-3 minutes to ensure that it was unhindered by the transmitter or harness. If the sparrow appeared to be behaving normally (balanced and perched easily and walked normally), we released it from the test cage. If the transmitter or harness seemed to hinder the sparrow in any way, we removed the transmitter and attached a new transmitter and harness following the same protocol. To further monitor potential effects of the transmitter, after release, we closely monitored each sparrow's activity for the following two days by recording its location twice daily and closely observing its flight behavior.

After approximately 50-55 days, as transmitter batteries weakened, we recaptured radio-marked individuals using the technique described above. We again recorded each sparrow's measurements, and if the sparrow appeared healthy, we replaced the transmitter following the same attachment protocol. Transmitter replacement allowed us to obtain data on selected individuals for extended periods. All active radio transmitters were removed from sparrows at the end of both study periods. If we identified a malfunctioning transmitter or a sparrow wearing a failed transmitter, we always attempted to recapture the individual and attach a new transmitter.

Determining effects of transmitters

Ideally, testing for effects of the transmitter or harness on sparrows would involve comparing behavior and condition between similar numbers of radio-marked and unmarked sparrows. However, this was not feasible due to the secretiveness of sparrows and the inability to capture the same unmarked individuals repeatedly over time without the aid of radio telemetry. Consequently, we looked for potential effects of the transmitters over time for radio-marked sparrows by comparing physiological and behavioral characteristics for radio-marked sparrows to these same characteristics for sparrows without transmitters that we captured incidentally. In addition, we inspected radio-marked sparrows closely for evidence of physical injury that might be directly related to the transmitter or harness, such as abrasions. The condition indices that we chose to monitor do not have standards, and we could not evaluate the sensitivity of these indicators to physiological stress that the sparrows may have incurred as a result of handling and transmitter attachment. However, we believe that we could reasonably detect serious physiological limitations for radio-marked sparrows before these limitations were manifested in injury or death. Additionally, using a combination of several indices instead of just one probably increased our odds of detecting detrimental effects.

We regularly recorded three indices of condition for all sparrows we captured: fat score, mass, and molt progression. All of these characteristics are related to the sparrow's energy balance. Changes in mass, though subject to some degree of variation tend to indicate whether sparrows are maintaining, increasing, or losing body mass. Similarly, the amount of visible subdermal fat tends to indicate a sparrow's ability to store energy. Lastly, molt is a very energy-intensive undertaking, and birds that are stressed or unhealthy often exhibit molt retardation, fail to complete molt, or show deformities in feathers such as fault bars. By monitoring these three condition indicators, we believe that we could detect energy limitation related to the presence of the transmitter or harness if it was occurring.

We also monitored two behavioral characteristics as part of our evaluation of transmitter effects: response to flushing and flushing distance. Again, there is not a standard for this index, but we would not expect a sparrow that was suffering severe energy limitation to flush similarly to a sparrow that was not under such limitation. This index was intended to provide only short-term information because some unknown degree of change is expected as sparrows become accustomed to regular flushing by the observer. For all sparrows we located, we recorded the

sparrow's flight distance and direction. Flushing distances were represented as the straight-line distance between the location from which the sparrow flushed and the point where it alighted. These distances were visually estimated.

Radio telemetry and location recording

The normal transmitter range on the ground was 400-800m, but this range was considerably greater if the sparrow was perched high in vegetation or was in flight. Individuals with transmitters were radio-tracked daily from the ground. We tracked each bird's signal using a portable telemetry receiver and directional yagi antenna and closed in on the transmitter signal until the sparrow flushed. In this manner, we were usually able to determine the exact location from which the sparrow flushed. If we could determine this location within 0.5 m, we conducted habitat measurements (see below). If we were unable to determine the exact location from which the sparrow flushed, we only recorded its approximate location, flight distance, and flight direction.

We used triangulation (White and Garrott 1990) to known reference posts (Figure 3) to record sparrow locations on study plots. When sparrows traveled off study plots into areas where we had not established reference posts, we recorded sparrow locations using a Garmin GPS 12 non-differentially correcting, hand-held global positioning unit. To reduce the effects of error intentionally introduced into GPS systems (selective availability) each location was recorded as the 2-minute average of positions collected each second by the unit. We also assessed location accuracy using this system (see Appendix 1).

We placed 11 reference posts at the EI site and 16 at the HR site during the first field season and added 10 reference posts to the EI site and 1 reference post to the HR site during the second season. In addition, we placed 3-5 reference posts in five other areas where radio-marked sparrows settled off our study sites during the second field season. Reference posts, spaced approximately 200 m apart throughout each site served as reference points used: (1) in triangulation to record sparrow locations, and (2) where we regularly measured water levels (see below). Each post was made of 3/4-inch (1.9 cm) diameter PVC pipe and was placed rigidly into the ground to the depth where it was resting on bedrock. Each post was marked at 0.5-cm increments upward from the base for recording water levels and was flagged with a unique color combination at the top to facilitate identification and improve sightability. We recorded the

exact location of each reference post using a Trimble Pathfinder Pro GPS system. To ensure accurate post locations, we averaged > 200 differentially-corrected GPS positions. Tests of the GPS system suggested that post locations were accurate to within 1-2 meters.

All daily radio tracking was done on foot. If we ever failed to locate sparrows using telemetry equipment in areas where they had recently been located, we expanded the search area and listened for the transmitter signal within 1-3 km² of the sparrow's last location. If we still failed to locate the transmitter, we began intensive searches within the sparrow's normal activity range. In doing this, we assumed that the sparrow might have removed the antenna, in which case the transmitter's detection range could be shortened to as little as 50m. If this effort still failed to locate the sparrow, we conducted low-level aerial surveys (Cessna 172) over the larger study area while continuing extensive ground-based searches. From the air, a normally functioning transmitter could be detected up to 2 km away. We flew transects 2 km apart across the full extent of the non-forested areas of the southern Everglades for a radius of 10 km from the sparrow's last location. If aerial searches still failed to locate the sparrow, we tested for transmitter failure by attempting to locate the sparrow within its normal activity areas via rope-dragging. If we observed any sparrows in the area we were searching, we attempted to capture them to determine if they were wearing a failed transmitter. In this manner, we were able to determine effectively the status of many "missing" sparrows.

In addition to the telemetry data, we recorded locations of resighted color-banded sparrows whenever possible. We generally did not actively seek to resight sparrows, but because we regularly encountered banded sparrows, we recorded band information whenever possible. Observers were instructed to record locations of sparrows only for which they could confidently determine the color and arrangement of all colored leg bands. Locations of these banded birds were recorded in the same manner as for radio-marked sparrows.

Movements and Home Range

We defined a sparrow movement as the straight-line distance between consecutive locations. We generally sought to locate sparrows daily, consequently, movements were generalized as the distance traveled in the course of an approximately 24 hour period.

We estimated home ranges using adaptive kernel home range estimators (Worton 1989) in the program Calhome (Kie et al.1994). Adaptive kernel home range estimators are based on a

weighted point probability distribution function with weighting that emphasizes the centrality of the distribution. We defined sparrow home ranges using the 90% probability contour to reduce the effects of outlying locations on home range size. All home range contours were calculated using a zero smoothing parameter (Kie et al. 1994).

Hydrology and water measurements

We measured water depth daily at reference posts throughout the HR and EI study sites to examine hydrologic patterns in the overall study area. We recorded water depth at the reference post near the entrance to each site (primary reference post) on every visit to the study site. In addition, we regularly recorded depths at other reference posts across all study sites but did not record depths at each post every day. Depth measurements on the posts were not calibrated to any standard because the changes in water depth were our primary focus. However, for each measurement we recorded water depths at distances of 1-3 meters from the post in each cardinal direction and then averaged these measurements to determine the average water depth at the post.

We developed an elevational model for our two primary study sites for the purposes of determining the availability of wet and dry micro-sites and investigating the degree of variation in water depth across these study sites. We used a method similar to that used by Nott et al. (1998) to construct a conservative, small-scale pseudotopography for each study site based on the depth of inundation during wet periods. By subtracting the water level at the site's primary reference post from the minimum water depth measurement recorded at each vegetation measurement point (see below) each day, we determined the elevation at each habitat measurement point relative to the control post. We eliminated all points within dense sawgrass clumps or sways to avoid the effects of solution holes and other small depressions on the overall topography. In addition, we eliminated all points recorded during dry periods (water at control points < 6 cm) to ensure that nearly all of the site was inundated when we conducted measurements.

We subsequently interpolated a digital elevation model for each site within the IDRISI Version 2.0 GIS software (Clark Labs for Cartographic technology and Geographic Analysis 1997) using distance-weighted averaging of elevation at points, with the reciprocal of the distance between adjacent points acting as the weighting factor. In addition to the

pseudotopography, we tested for variation in rates of change over time between our study sites. We also compared water depths we recorded on our sites to depths recorded at nearby hydrological monitoring stations.

Determining Habitat Associations of Sparrows

Landscape-level habitat associations

We identified several landscape features including tree islands, cypress domes, isolated trees, forested boundaries, old grove agricultural areas, and old-field areas, within our study area. When analyzing telemetry data for landscape level habitat associations, we primarily described either positive or negative associations of sparrows with these landscape features. We did not undertake a quantitative analysis of these associations for the purposes of this report.

Selection of micro-habitat characteristics

We measured habitat characteristics across the overall study area using a point-based sampling regime. To test for habitat selection by radio-marked sparrows and to facilitate comparisons between study sites, we measured habitat characteristics at random points across the study sites and at accurate sparrow locations. Accurate sparrow locations were those for which observers confidently recorded the location from which sparrows flushed to within 0.5 m.

Random points were selected relative to a series of parallel transects spaced 100m apart that traversed each study site. Stratified random numbers (0-50 m) determined the distance the observer traveled down the transect. A second random number determined whether the observer moved left or right off the transect, and a third random number (0-50 m) determined the distance the observer traveled perpendicular to the transect to establish the sample point. After completing measurements at each random point, the observer returned to the transect and started the process again, slowly progressing down the length of the transect.

We measured the following habitat variables within a 1-m radius circle centered on each sparrow location and each random point.

- 1) Water depth and soil depth at the center point and at points one meter from the center point in each cardinal direction. In analyses, we used these values to obtain average water and soil depths and variance in these depths, as well as depths at the center point.

- 2) Direction and distance from the center point to the nearest clump of sawgrass. We defined a sawgrass clump as a dense sawgrass stand (>70% sawgrass cover) that was taller than the surrounding vegetation and had a diameter > 1 m. Sawgrass clumps generally occurred in small solution holes.
- 3) Maximum and effective height of the vegetation. Maximum height was the height of the tallest vegetation at the center point. Effective height was determined by placing a metal rod horizontally on top of the vegetation at the center point and measuring the distance from the soil surface to the bottom of the rod. Effective height is an index of the structural height of the vegetation at a point.
- 4) At each sample point, we described the dominant vegetation following Daubenmire (1959). We recorded percent canopy coverage of 6 vegetation variables - *Schizocyrium*, sawgrass, rush, litter, bare ground, and shrub - within a 1/8 m² rectangular quadrat centered on each sample point. "Rush" was composed of several structurally similar species that we assigned to this structural category - muhly, black-topped sedge, beak rushes (*R. katespii* and *R. inundata*), and spike rush (*Eleocharus* sp.). During the second field season, we estimated percent cover separately for black-topped sedge. The litter category included litter of all species. Percent canopy coverage was determined by visually estimating the cover of each vegetation variable and assigning it to one of six broad cover categories. These categories were 0-5%, 6-25%, 26-50%, 51-75%, 76-95%, and 96-100% (Daubenmire 1959). We did not estimate vegetation cover within cypress domes and tree islands.

To analyze micro-site vegetation data, we first conducted descriptive analyses of sparrow and random locations and compared the frequency occurrence of vegetation cover classes at the different study sites. Initially, we tested for correlation among variables to ensure that we met assumptions of the analysis techniques. We determined a priori that we would consider variables with an R-value < 0.70 to be uncorrelated.

To evaluate selection of micro-habitat characteristics by sparrows, we employed a use vs. availability design as outlined by Manly et al (1993). Sparrow locations were classified as the "used" resources, and the random points across the study sites constituted the "available" resources. We used measured habitat variables and logistic regression analysis (Hosmer and Lemeshow 1989, Manly et al. 1993) to evaluate selection by sparrows. These procedures fit

logistic regression models with dichotomous dependent (outcome) variables by the method of maximum likelihood (Menard 1995).

We used stepwise multiple logistic regression analysis to create parsimonious habitat selection models for each site as well as a single model combining both sites. Logistic regression models describe the relationship between a dichotomous outcome variable and a series of independent (explanatory) variables (Hosmer and Lemeshow 1989). In our logistic regression models, the dichotomous outcome variable was whether a habitat measurement point was a sparrow location or a random location, and we sought to determine which habitat variables best distinguished between the two types of points. Because our vegetation cover classes represented categorical data, we created a series of dummy-coded variables for each vegetation type and retained the absence of a vegetation type at a point as the referent group for each set of dummy variables.

To eliminate effects of cover categories with few occurrences in logistic regression models, we combined sparse vegetation cover categories. We defined sparse categories as those with occurrence of a particular vegetation cover class at less than 10% of the points within each study area. In addition, if we recorded less than 10 occurrences (<1%) within a particular vegetation cover class, we eliminated all points containing those values to improve the interpretation and fit of models. At both sites, these rules eliminated the cover categories above 50% for muhly and sawgrass and categories over 75% for litter and open cover types. Rush cover categories over 25% were also eliminated.

We constructed parsimonious logistic regression models using a top-down modeling approach with both forward and backward steps in which we removed variables that did not aid in predicting the outcome variable. To identify potential variables for elimination, we used the Wald statistic. After we removed a variable, we then tested whether the removal significantly reduced the predictive power of the model using likelihood ratio tests at an alpha-level of 0.05 (Hosmer and Lemeshow 1989). If removal of a variable resulted in a significant loss of predictive power of the model, we tested whether the addition of each previously removed variable increased the model's discrimination capabilities. With this approach, final models were those containing the fewest variables that did not differ from the saturated model (the model containing all habitat variables) in discriminatory power. In this manner, we produced parsimonious models that distinguished between random and sparrow locations. We also tested

final models against a constant-only model to determine whether addition of any habitat variables aided in discrimination.

We tested each model for goodness-of-fit using the Hosmer-Lemeshow goodness of fit chi square based on deciles of risk (Hosmer and Lemeshow 1989). In addition, we estimated the ability of each model to discriminate between sparrow and random locations as expressed by the area under the ROC curve. This curve is obtained by plotting sensitivity against specificity for each model; the area under the curve then represents the probability of correctly classifying any one observation as a sparrow location or a random location and provides another way to evaluate the discriminatory power of each model (Hosmer and Lemeshow 1989).

Relationships between habitat use and water levels

To investigate relationships between habitat use and water depths, we only used sparrow locations within each study site. The dataset for this analysis was, again, the habitat measurements that we collected at each of these locations. We used Kruskal-Wallis non-parametric analysis of variance with Bonferroni-adjusted alpha levels to test the null hypothesis that sparrows did not use vegetation cover types differently under different depths of inundation.

For this analysis we compared sparrows' use of habitat cover types relative to the daily water depth at the reference point for each site. We used this relatively conservative approach to avoid biases related to local variation in hydroperiod and correlation with vegetation cover. Water depth was considered the dependent variable, and analyses were conducted for each variable pooled across both sites. The experiment-wise alpha level was maintained at 0.05. We used multiple comparison tests to determine which cover classes led to significant ANOVA results.

Sparrow distribution across the landscape

We evaluated sparrow distribution during the non-breeding season using rope-dragging transects. With this technique, two people drag a 25-m nylon rope between them along a transect. One-meter trailing ropes were tied to the main rope approximately every 1.8 m along the length of the main rope, and two plastic bottles were tied to the trailing ends of these ropes to create noise and additional disturbance to the vegetation as the rope was dragged over the prairie. This technique was designed to create a large disturbance to the low vegetation to flush nearly all birds within the transect without damaging the vegetation.

During the first field season (1997-1998), we placed 2 parallel 800 x 25 m belt transects (each transect covers 1 ha) at each of 7 sites and a single transect in one additional site. Six of these sites were known to support sparrows during the breeding season (these sites coincided with breeding season study plots; Lockwood et al. 1999a). Additional details of the technique are presented in Fletcher et al. (2000). We additionally tested the technique in relation to standardized point counts but found transects to be more effective (Fletcher et al. 2000).

During the second field season, we applied the same rope-dragging technique but applied it in conjunction with 34 point-based plots (200 m radius). We randomly selected this sample of 34 points from the 213 point count locations used to estimate breeding season sparrow population size and distribution (Bass and Kushlan 1982, Pimm et al. 1997). These points are located at the intersections of a 1 km grid and are uniformly distributed throughout the potential habitat area within the Ingraham Highway population of Cape Sable seaside sparrows (population B; Lockwood et al. 1999a). The goals of this survey were to use these points (1) to assess sparrow presence within the Ingraham Highway population during the non-breeding season and (2) to compare breeding and non-breeding season distributions.

Using a differentially correcting GPS, observers walked to each point and set a temporary center post. Observers then set up three rope-dragging transects within a 200 m radius circle (one 400m transect and two 320 m transects, cumulative area of 1.6 ha) about the center point. Transect width was 25 m. One observer maintained the established transect while the other observer identified and recorded all birds flushed during the course of the sampling. Transect lengths varied slightly among plots because of changes in direction to avoid tree islands, cypress, and other objects.

Estimating survival

We estimated survival rates for radio-marked sparrows during both years of the study. During the first field season, we primarily attached transmitters to adult sparrows, although sparrows captured after December were classified as unknown age due to our inability to distinguish adults from juveniles. During the second field season, we attached transmitters to adult and juvenile sparrows but did not radio mark any sparrows for which we could not assign age class.

We modeled survival for radio-marked sparrows using Program MARK, a comprehensive application for the analysis of marked individuals (White and Burnham 1999). We used the known-fate model in MARK, which is appropriate for data derived from radio tracking studies to estimate survival for radio marked sparrows. Known fate data assume that there are no nuisance parameters involved with animal captures or resightings but that resighting probabilities equal 1 (the sparrows can be located via the radio transmitter). Therefore, no resighting parameter (ρ) is estimated and the use of goodness-of-fit tests to evaluate capture-recapture assumptions is not required (White and Burnham 1999). The known-fate model in MARK is analogous to the Kaplan-Meier analysis with a staggered entry design (Pollock et al. 1989) in that it calculates period-wise survival estimates using individual sparrows, which incurred one of 3 possible outcomes - survival throughout the entire study period to transmitter removal, death, or censorship (disappearance). Censored individuals are included in survival calculations for all periods during which their fate is known but are excluded from the period in which they disappear (White and Burnham 1999). Sparrows that disappeared presumably due to transmitter failure were classified as censored. We estimated weekly survival rates then calculated an overall survival rate for the entire study period for each of the two years separately.

All models were developed using the design matrix in MARK. The design matrix is a matrix containing the dummy variable structure that codes the design for each particular analysis. Use of the design matrix within MARK enables fitting a wide variety of complex analytical models quickly and easily (Cooch and White 1999). We tested whether survival of sparrows varied by age (adults or juveniles) or by time (week) across the entire study period for each year of the study, 31 weeks for 1997-1998 and 38 weeks for 1998-1999. To compare models within each year, we used Akaike's information criterion (AIC), which permits objective selection of the "best" model (Akaike 1973, Burnham et al. 1995). Competing models (within 10 AIC units) were also evaluated with likelihood ratio tests (LRT) (McCullagh and Nelder 1989) generated by MARK to determine the most parsimonious model based on all combinations of effects.

We also calculated survival based on resightings of banded sparrows that were recorded during the second field season. We only used resightings from the second field season because resighting banded sparrows was not a primary goal during the first field season. During the second field season, we invested extensive effort in resighting sparrows and did so over our entire study area.

We used the Cormack-Jolly-Seber model (Cormack 1964, Jolly 1965, Seber 1965) in program MARK to estimate survival rates based on resightings and recaptures of previously banded sparrows. Along with estimating a survival parameter, this model provides estimates of the resighting probability during each time period (week). For the resighting dataset, we developed models that tested effects of age (adults or juveniles) or time (week) and on both resighting and survival parameters. As for the known-fate models, we compared CJS models using AIC values. We used goodness-of-fit tests to evaluate capture-recapture assumptions for the CSJ models (White and Burnham 1999).

Investigating Genetic Relationships

We provided data to supplement earlier investigations of genetic relationships among seaside sparrow populations throughout the species' range. Mitochondrial DNA (mtDNA) was isolated from liver tissue of a salvaged Cape Sable seaside sparrow and from blood samples collected from 10 individual sparrows and stored in lysis buffer. DNA was obtained from the blood samples using phenol-chloroform extraction and was amplified using long-PCR (Nelson et al. 1996). Genetics analyses were conducted at the Department of Genetics, University of Georgia. Complete details on techniques are reported in Nelson et al. (2000). Genetic analysis was based on the matrilineal mtDNA.

The linear (not closed-circular) amplifications of mtDNA were subjected to digestion by the same suite of 18 restriction enzymes employed in earlier analyses of seaside sparrow mtDNA (Awise and Nelson 1989). Restriction fragments were electrophoresced through agarose gel with fragment size compared against a 1-kb ladder standard. Digestion profiles were compared to results of previous analyses detailed in Awise and Nelson (1989).

Diet

It is nearly impossible to obtain reliable information on the diet of Cape Sable seaside sparrows during the non-breeding season due to their extreme secretiveness. Lockwood et al. (1997) obtained some information on diet during the breeding season when food items could be readily observed as they were carried to nestlings. However, those data may not accurately reflect the diet of sparrows during the non-breeding season, when energetic demands, food availability, environmental conditions, and sparrow behavior are different from the breeding season.

Because we could not directly observe sparrows foraging during the non-breeding season, we collected fecal samples from sparrows during handling. Samples were stored in vials containing 1 ml of 70% isopropyl alcohol. Samples were scanned for identifiable particles under a 15-30 magnification dissecting scope. Particles were sorted, and any particle that could be identified or classified was recorded. We did not attempt quantitative analysis of these data but present only descriptive results here.

Parasites and disease screening

During the second field season, we screened all captured sparrows for ecto-parasites despite the lack of absence of ecto-parasite observations during the previous season. Screenings involved thoroughly checking feathers and skin around the head, neck, and ears for ecto-parasites. We also checked flight feathers of one wing for presence of parasites. When we captured a sparrow, we blew gently on the regions listed above to separate the feathers. Whenever possible, parasites and parasite eggs were counted, but when loads were heavy, the load was estimated. We additionally collected a sample of ecto-parasites from 12 individuals and sent them to Dr. J. W. Mertins of the National Veterinary Services Labs, Ames, Iowa, for identification.

From the 10 blood samples collected for genetic analysis, we prepared blood smears for hemoparasite and disease screening. To prepare smears, a drop of blood was placed on a microscope slide, and spread using surface tension to provide a 1-cell thickness of blood across the slide. The slide was air-dried then fixed by dipping in 100% ethanol and again air-dried. We provided slides to Dr. D. Forrester in the Department of Veterinary Medicine, University of Florida, Gainesville, who screened the samples for parasites.

RESULTS

Trapping and banding

We captured Cape Sable seaside sparrows during the periods 26 July 1997 through 28 February 1998 and 16 June 1998 through 8 March 1999. During this period, we performed 240 captures of Cape Sable seaside sparrows (72 captures during the first field season and 165 captures during the second field season). We captured and banded 92 previously unmarked sparrows and recaptured 13 sparrows originally banded by S. Pimm and the breeding season crew (Appendix 2). The remaining 135 captures were recaptures of banded birds we had

previously encountered in the course of the study, predominantly recaptures of radio-marked sparrows. We recaptured individual sparrows 1-8 times throughout the course of the study.

Transmitter Attachment

We attached transmitters to 45 sparrows (20 during the first field season and 25 during the second field season, Table 1) and conducted 151 transmitter attachments. No injuries or mortalities occurred during capturing, handling, or transmitter attachment. Four transmitters fell off shortly after attachment, and during the first field season we removed one transmitter approximately 12 hours after attachment due to the sparrow's apparent difficulty with the transmitter or harness. We attached a transmitter to this same individual during the second field season, however, without difficulty. We never failed to recapture a sparrow with a functioning transmitter for transmitter replacement, and we also recaptured several sparrows with broken or malfunctioning transmitters.

We documented several transmitter failures during the second field season. In over half of these cases, we successfully recaptured the sparrow and attached a new transmitter. On at least three occasions, we observed a sparrow with a transmitter but were unable to recapture it. In seven other cases, we never again observed the radio-marked sparrow.

Effects of Transmitters and Harness on Sparrows

Sparrow mass and fat scores

Transmitters weighed approximately 1.1g; this amount ranged from 5.2% - 6.7% of sparrows' body mass. Because we were not able to consistently recapture sparrows without transmitters, we were unable to make direct comparisons of condition changes between marked and unmarked sparrows. So, over time, we accumulated data for mass, fat scores, and molt progression of sparrows we captured that had transmitters and those that did not, then combined and compared these data by month (Figures 4-6). Generally, these indices revealed that there were no consistent differences in either condition index (Figures 4-6). (Weight of the transmitter was not included in mass measurements taken for recaptured radio-marked sparrows.)

Sparrow mass, fat scores, and molt varied substantially over both study periods in a consistent seasonal pattern (Figures 4-6). Despite these seasonal variations, sparrows with transmitters were consistently similar in mass and fat condition to sparrows without transmitters within monthly periods, and both groups exhibited similar patterns of change throughout the year

(Figures 4-5). Sparrows with transmitters also did not deposit fat or gain weight more slowly than sparrows without transmitters. Neither index indicated any detrimental effects of transmitters on the sparrows over time.

Plots of sparrow mass changes between successive transmitter attachments compared to the relative transmitter weight (proportion of a sparrow's body mass) revealed a significant positive relationship (linear regression, slope = 0.812, $P = 0.001$; Figure 7), although this result may have been disproportionately influenced by a relatively large weight loss during one battery cycle by one sparrow carrying a relatively light transmitter (Figure 7). While sparrows with heavier transmitters may increase muscle mass to some degree, it is unclear whether this reflects an effect of the transmitter or attachment. Plots of changes in fat scores against relative transmitter weight again revealed a positive relationship (regression slope = 0.887, $P = 0.070$; Figure 7), but the slope was not significantly different from zero. The seasonal patterns of mass change and fat accumulation and loss may be a confounding factor in evaluating potential effects of the transmitter and harness on sparrows. However, our results suggest that within the range of transmitter weights that we used, effects on sparrows, if any, were negligible.

Flushing distances

During both field seasons, we observed similar patterns in the distances that individual sparrows flew in response to disturbance. During both field seasons, flushing distances generally declined slowly as the field season progressed, although regression analyses that we conducted during the first field season failed to exhibit significant trends (Dean and Morrison 1998). Vickery and Dean (1997) reported a similar result in their non-breeding season study of radio-marked Florida grasshopper sparrows (*A. savannarum*).

A decrease in average flushing distance over time could reflect increasing physiological stress caused by the transmitter. However, the observed patterns of slow decline in flight distances over time could also be the result of behavioral changes as sparrows become accustomed to flushing by observers. Individual tolerance by sparrows of observers in close proximity varied greatly among individuals and over time. Early in the season, sparrows generally flushed when observers approached to within 5-10 m, depending largely on the surrounding vegetation. Near the end of the study period, some sparrows regularly allowed observers to approach to within 1 m before flushing. If flushed multiple times, however,

sparrows generally flew increasing distances (up to 300 m), again suggesting that they were not energy-limited or physically hindered by the transmitter. Overall, we believe this pattern of slow decline in flushing distance over time represents a behavioral adjustment resulting from daily encounters with observers over a 9-month period.

Radio Telemetry and location recording

Overall, we recorded a total of 4,411 locations of radio-marked sparrows during both field seasons; 1,721 during the first season and 2,690 during the second season. Most of the locations we recorded for individuals were temporally separated by ≤ 30 hrs, though we located individuals less frequently during inclement weather and when sparrows moved to remote areas where access was difficult. Except for aerial searches for “lost” sparrows, all radio tracking was done on foot.

Most sparrow locations were obtained using triangulation to reference posts, but we used non-differentially corrected GPS to record 466 locations of radio-marked sparrows that had traveled off our study plots and into areas where we had not established reference posts. Triangulation to reference points on study plots yielded an average maximum error of 12.4 m, although errors may have been greater for locations off the study plots and in areas where reference posts provided only marginal triangulation. Using these methods, GPS points recorded without differential correction yielded a 95% confidence radius of 46 m around sparrow locations (Appendix 1). Errors using differentially corrected GPS were generally < 5 m.

Movements – radio telemetry

We calculated 4,341 movements made by individual sparrows. We represented these movements as the straight-line distance between consecutive locations for individual sparrows. The majority of movements that we recorded using radio telemetry ranged from 0-400 m (Figure 8). However, in several instances, we recorded movements > 500 m between consecutive locations. The longest movement we recorded occurred during the first field season in which an adult female sparrow traveled 5.99 km between consecutive locations. Another relatively long distance movement was recorded during the second field season, in which a juvenile sparrow traveled 4.92 km between consecutive locations.

While rare, these longer movements indicate that sparrows are capable of traveling relatively long distances across contiguous prairie habitat. The longest cumulative movements

that we recorded took place over several consecutive days, and sparrows probably traveled consistently in one direction, overall, during this period, while moving to these new areas. We observed this pattern during a long-distance movement by another adult female sparrow that traveled from the HR site to a new area approximately 4.5 km west. She moved to the new area over the course of a few days, traveling between 0.4 and 2.5 km each day.

For most sparrows, the average distance between consecutive locations showed relatively little variation over time (Figure 9). Distance between consecutive locations showed more variation among juvenile sparrows (Figure 9). These juveniles were individuals that we monitored early in the non-breeding season when this age group typically showed patterns of longer movements (see below).

The overall distribution of distances between consecutive locations for radio-marked Cape Sable seaside sparrows shows a strong leptokurtic distribution with a mode between 50m and 100m (Figure 8). Comparisons of the distribution of distances among study sites and years revealed no differences ($\chi^2 = 34.13$, $df = 27$, $P = 0.16$). The distance distributions also did not differ between sexes for adult sparrows ($\chi^2 = 10.59$, $df = 9$, $P = 0.31$). However, the distribution distances between consecutive locations for adult and juvenile sparrows did yield differences ($\chi^2 = 19.66$, $df = 9$, $P = 0.02$; Figure 10). Inspection of standardized residuals for these two distributions indicated no differences in frequency of movements within the distance classes < 450 m, but juvenile sparrows made movements in the longer distance classes more frequently (Figure 10).

Long distance movements, represented as the upper 10% and 5% of the distribution, were those movements over 276 and 362 m, respectively, for adult sparrows. Movements in the upper 5% of the distribution correspond roughly to the diameter of a circular area equivalent in size to the average adult sparrow home range. Movements in this upper tail may represent permanent movements away from established home ranges subsequent to which the sparrow established a new home range in another area. These movements may also represent exploratory movements away from established home ranges. The occurrence of relatively long-distance movements by adult sparrows did not vary substantially over time during either season ($\chi^2 = 4.44$, $df = 6$, $P = 0.62$).

The upper 10% and 5% of movements made by juvenile sparrows were those above 345 and 519 m, respectively, again indicating a right-shift in the distribution for juvenile sparrows

relative to adults. The occurrence of longer movements by juvenile sparrows was not consistent over time, however. A larger proportion of longer movements occurred in August relative to other months ($\chi^2 = 14.33$, $df = 6$, $P = 0.03$); 34% of the movements in the upper 5% of the distribution occurred during August (Figure 11).

Movements – resightings

In addition to radio telemetry, we recorded observations of color-banded birds throughout both years of the study. We resighted and identified color-banded sparrows on 250 occasions. We resighted 76 color-banded individual sparrows and observed each from 1-10 times during the course of the study. Of these, 62 were juveniles and 14 were adults.

Of the 62 juvenile sparrows we resighted, 31 were originally banded as nestlings by Pimm et al. (1997). These sparrows accounted for the majority of the color-banded sparrows we resighted. The majority of resightings of both juvenile and adult sparrows occurred from June through August, when adult sparrows were still exhibiting territorial behaviors and juvenile sparrows were gregarious, vocal, and readily observable. The sparrows' increasing secretiveness later in the year made locating and identifying color-banded individuals progressively more difficult.

The distribution of distances between consecutive locations for banded-only sparrows (developed from resighting data, resighting distribution) was similar to this distribution obtained from the radio-telemetry data (telemetry distribution) (Figure 12). However, when we investigate the resighting distribution for juvenile sparrows with their nest locations (Pimm et al. 1997, Lockwood et al. 1999b) included as the point of origin for each movement, this distribution is strongly right-shifted relative to the telemetry distribution. Because we resighted most juvenile sparrows early in the year when juveniles are exploring and dispersing (Dean and Morrison 2000), we suspect that the right-shifted distribution reflects a dispersal period for juvenile sparrows.

To test this hypothesis, we compared distances traveled from nest sites to the first resighting and distances between the first and last resightings (those most distantly separated in time) for individuals whose nest sites were known. We found that distances from nests to first resightings were longer than distances between first and last sightings (Mann-Whitney $U = 979.00$, $P = 0.000$). We compared the time interval between observations for the two groups,

again using the Kruskal-Wallis ANOVA and found that they did not differ (Mann-Whitney $U = 671.00$, $P = 0.89$). These results supports our hypothesis that fledgling sparrows travel widely soon after independence then become more sedentary later in the non-breeding season.

Resightings and recaptures of previously banded sparrows also provided information on recruitment and breeding dispersal. We observed six color-banded individuals that represent recruitments into the study population. These sparrows were originally banded either as nestlings ($n = 3$) or as fledglings ($n = 3$) and were subsequently observed > 1 year after banding. The three sparrows initially banded as nestlings were observed 447, 706, and 1673 m from their nest locations (mean $942.28 \text{ m} \pm 373.15 \text{ SE}$). The three sparrows that were originally banded as fledglings were all originally banded on the HR study site during the first field season. They were subsequently observed > 1 year later 206, 407, and 2702 m from their original banding locations (mean $1105 \text{ m} \pm 800.60 \text{ SE}$).

Resighting data also provided documentation of a breeding dispersal by an adult female sparrow. During the second field season, we observed and subsequently captured this individual on the HR study site. She was originally banded as a breeding adult on the Ingraham North study plot (Pimm et al. 1997) so she was at least 2 years old when we recaptured her. This individual had been originally banded a minimum of 1.6 km from where we observed her, and she remained on the HR study plot into the breeding season of 1999. One additional color-banded sparrow, originally banded as an adult on the Alligator Hammock study plot, was observed on the HR study plot during the first field season and may have represented a breeding dispersal. This individual had moved > 4 km from its original banding location, but we were unable to determine where this sparrow settled following our observation of it on the HR site.

Home Ranges

All sparrows that we radio-tracked for more than a few days exhibited a centered movement pattern consistent with the home range concept. Sparrows did not move widely across the landscape but generally remained within specific areas. Combining data from both field seasons, we conducted home range analysis for 38 individual sparrows for which we recorded > 20 locations (Table 2, Figures 13-17). Home range analyses for 7 sparrows revealed > 1 spatially distinct home range (Table 2). Additionally, one female sparrow established a home range > 5 km from where she was originally captured, but we only report one home range

for this individual because she departed the area of her initial capture only 4 days after we captured her. We do not know whether she had an established home range in the initial area prior to capture. However, this female was captured at the end of the breeding season and still showed a well-developed brood patch. We think that we captured her at or near her original breeding territory, and the subsequent movement represented a breeding dispersal. She did not return to the area of her initial capture the following breeding season.

Home ranges for individual sparrows averaged 17.1 ha (± 11.6 SD) in size and ranged from 5.7 - 55.5 ha (Table 2). Average home range sizes were similar for male and female sparrows (14.6 and 16.7 ha, respectively, $t = 0.39$, $P = 0.70$). Adult and juvenile home ranges did not differ in average size ($t = -1.16$, $P = 0.25$) although home range size of juvenile sparrows (20.90 ha) was on average 5.2 ha larger than that of adult sparrows (15.70 ha).

Juvenile sparrows may be more likely to use multiple home ranges than adults; 4 of the 8 sparrows with > 1 home range were juveniles, two of the remaining 4 sparrows were of unknown age, and two were adults. In 6 of 7 cases of multiple home ranges, sparrows did not return to previously established home ranges once they began using a new area. In the cases where sparrows returned to previously established home ranges, the spatially distinct ranges were separated by distances of 100 - 300 m, which is generally less than the diameter of an average home range.

The largest cumulative home range sizes were for those individuals that maintained multiple home ranges. Each distinct home range used by an individual sparrow generally had characteristics similar to home ranges of sparrows that maintained only a single home range. The average size of each distinct home range for individuals that had multiple home ranges was 15.98 ha (± 12.06 SD). This value is similar to the average home range size of all adult sparrows in our sample (15.70 ha).

Hydrology and water measurements

We monitored water depth at reference points across the study areas on a daily basis to determine both large-scale changes and local variation in water levels. The variation we recorded was striking, with water levels varying at a single point from several cm below ground to over 30 cm above the ground (Figure 18).

During the first field season, we began field work in July, which was well after the rains had started. Water depths were approximately 5-10 cm across most of the study area, and they fluctuated without dropping substantially for several months. However, plots of water levels recorded at the nearby P46 recording station indicated that water levels had been nearly 40 cm higher in the area only one month prior to our arrival.

High water levels generally occurred at the same time on the two study sites and resulted from rainfall both on the sites and nearby. We observed small differences in peak water levels between the sites on several occasions, and these probably resulted from local variation in rainfall patterns. For example, on 17-18 September 1997 water levels rose on EI by 3.9 cm but remained unchanged at the HR site.

Rates of drying varied substantially between the two sites, with water levels at the HR site dropping faster than at the EI site. The average rate of decline in water depth was 0.71 cm/day (± 0.41 SD) at HR, and 0.53 cm/day (± 0.50 SD) at EI. The rate of drying also varied depending on water depth, with faster decline in water levels generally occurring immediately following high water levels. This is most clearly illustrated by the rapid decline in water depth at P-46 immediately following the high water event in May 1997 (Figure 18).

Conservative pseudo-topographies of the core portions of each study area indicated substantial variation in small-scale elevations, and we recorded variation in elevation of 20 cm at the HR site and 30 cm at the EI site (Figures 19-20). This substantial variation in the elevation within relatively small areas (approx. 1 km²) makes prediction of water depth at any one point very difficult because even substantial increases in water depth (~ 20 cm) may not inundate all portions of our study areas. Accurate prediction of water depth at a point requires detailed information on local variation in elevation, local flow patterns, and large-scale topography.

Habitat associations and selection

Landscape-level habitat associations

Results from both years of this study suggest that the Cape Sale seaside sparrows are completely reliant on the open, contiguous marl prairies where they currently reside. Within this habitat type, there are a variety of habitat configurations and features that sparrows apparently respond to. We discuss these briefly below.

Sparrow use of most vegetation types appeared strongly associated with both season and hydrologic conditions, though it was difficult to distinguish between these factors in many cases. Sparrows regularly used tree islands, low shrubs, and large, tall sawgrass sways in the late summer when water levels were high, and they were often conspicuous, vocal, and gregarious when using these habitat features. Sparrows rarely perched high in these features, however, and almost never entered the centers of these tree islands, instead preferring to stay along their perimeters.

Sparrows regularly used old agricultural areas that were not shrub-dominated. These areas were generally characterized by deeper soils and greater plant diversity than the surrounding prairies. However, the old-grove agricultural areas that contained abundant shrubs were not used by sparrows, although sparrows occasionally perched along the edge of these habitat patches.

Sparrows generally avoided large tree islands and other more continuous, forested areas such as the Old Ingraham Highway corridor and the forested edge of the prairies at their northernmost extent. Sparrows also rarely used cypress. Sparrows occasionally perched in low, lone cypress trees but did not use taller cypress or enter cypress-dominated patches.

We never recorded sparrow use of the mangrove zone at the southern extent of the prairies. During the first field season, one radio-marked sparrow traveled to within a few hundred meters of the mangrove zone before stopping and establishing an apparent home range. Lone mangroves occurred across this landscape and this sparrow used them in the same manner as sparrows use small shrubs. However, sparrows apparently avoid denser growths of mangroves. Water depths are greater and graminoid vegetation density is lower in the mangrove zone, resulting in wet, open areas that are not similar to areas where we regularly observed sparrows. Spike rushes (*Eliocharis* sp.) were the dominant graminoids associated with mangroves, and we rarely observed sparrows using this vegetation type.

Micro-habitat selection models

We recorded micro-site vegetation characteristics at 2610 sparrow locations and 1964 random locations during the course of the study (Table 3). The vegetation cover classes that we used (*Schizocyrium* (bluestem), rush, sawgrass, black-topped sedge, graminoid litter, shrub, and open) effectively described nearly all habitats we encountered. Of these variables, shrub was the

most sparse, occurring in only 18 of all 4574 points, however we did not generally record vegetation cover within tree islands when conducting random point sampling, so this result is not surprising. We consequently removed this variable from further analyses. Of the remaining vegetation variables, black-topped sedge was least often recorded, occurring in only approximately 10% of the points. We also only recorded black-topped sedge during the second field season. During the first season, we considered black-topped sedge as part of the "rush" vegetation category. Black-topped sedge never accounted for more than 25% of the total cover at a point.

Schizocyrium cover ranged from 0-75% at points we measured. Cover of this type exceeded 50% in < 1% of all points. To avoid biased results due to few occurrences in density classes > 50%, we pooled observations of *Schizocyrium* at > 50% cover with observations in the 25-50% cover class. Other sparse vegetation cover categories that were pooled with lower categories included sawgrass cover > 75%, graminoid litter cover > 95%, open cover > 95%, and rush cover > 50%. All remaining variables were included in analyses.

Because we extended the coverage of random points on study areas during the second year relative to the first season at both sites, measurements of available habitat varied between years. Consequently, we report use and availability results separately for the two field seasons (Figures 21-25).

We constructed logistic regression models for each year and site (4 models total). In all cases, saturated models (containing all variables) produced better discrimination than constant-only models, suggesting that sparrows did consistently select habitat based on at least some of the characteristics that we measured. Both saturated and parsimonious models for each site by year combination consistently showed good fit (Hosmer-Lemeshow goodness of fit statistic, *P* values ranged from 0.09 – 0.98). Parsimonious models retained 2-8 of the original variables.

For both years, site- and year-specific models varied with respect to the direction of association of sparrow use with individual variables included in parsimonious models. Consequently, we did not develop overall habitat selection models but instead chose to focus on differences among sites and years.

Logistic regression modeling consistently showed that sparrow locations differed from random sites with respect to vegetation characteristics in both years and at both sites. However, sparrows seemed to exhibit variable responses to vegetation characteristics over time and space,

most likely in response to changes in environmental characteristics, season, or other factors. The various year- and site-specific models differed with respect to the associations between sparrows and individual variables and with respect to predictive power.

During the first field season, parsimonious logistic regression models produced fair discrimination between sparrow and random points (discrimination was 0.69 and 0.67 for HR and EI sites, respectively; Table 4). Parsimonious models for HR and EI contained 6 and 8 of the original variables, respectively, with 5 of these variables common to both parsimonious models: effective vegetation height, average soil depth, *Schizacryium* cover, open cover, and rush cover (Table 4). However, vegetation variables were differentially associated with sparrow locations between the two sites. For example, *Schizacryium* cover was positively associated with sparrow locations at the HR site, but negatively associated with sparrow locations at the EI site. Similarly, open cover < 50% was negatively correlated with sparrow locations at HR but was positively correlated with sparrow locations at EI.

During the second field season, site-specific parsimonious logistic regression models contained 5 and 6 of the original variables at the HR and EI sites, respectively. Four of these variables were common to both models (Table 4) and all but 1 (distance to clump) were common to both years. Similar to the first field season, the direction of association of some variables was inconsistent among the sites. The habitat selection models produced relatively poor discrimination during the second season, 0.60 and 0.58, respectively (Table 4).

We do not think that the apparent lack of discrimination observed during the second season is an erroneous result because vegetation sampling was more intensive during the second field season. Additionally, inspection of plots of vegetation cover type frequencies revealed greater similarity between random points and sparrow points during the second year relative to the first year (Figures 21-25).

Habitat use and water depths

The variability of models for micro-habitat selection and the poor discriminatory power of the models could suggest that there is not a particular habitat characteristic that Cape Sable seaside sparrows select within the marl prairie system. An alternate hypothesis, however, is that habitat selection by sparrows is not static over time.

Changes in the hydrologic conditions in the marl prairies may drastically limit the array of choices that Cape Sable seaside sparrows have during parts of the year. As water levels rise, certain micro-habitat features may no longer be available to the sparrows. Sparrows can then either relocate or adapt to the changing environmental conditions. Our extensive telemetry data indicate that sparrows do not shift their overall area of use during periods when the prairies are inundated. To test the hypothesis that sparrows change their use of a micro-habitat characteristic in response to changing water levels, we investigated habitat characteristics that sparrows used in relation to the hydrologic conditions. From the results, several clear and interesting patterns emerged.

Not surprisingly, linear regression of depth of inundation and the effective height of vegetation at sparrow locations shows a significant positive slope. The maximum vegetation height shows a similar pattern, indicating that sparrows are selecting sites with a higher structural component during wet periods.

Kruskal-Wallis non-parametric analysis of variance tests indicated that the depths of inundation at a study site are different when sparrows use different vegetation cover types (Table 5). All of the vegetation cover types we recorded were used differently by sparrows as water depths changed (Figures 26-31). Sparrows used areas of greater *Schizocyrium* cover with decreasing water levels (Figure 26). This vegetation does not provide much structural support for sparrows, and sparrows were probably only able to use areas dominated by this vegetation type when water levels were low. Sawgrass cover showed an opposite trend (Figure 27), with use of higher sawgrass cover occurring when depth of inundation was greater. The strong stems and leaves of sawgrass can easily support sparrows well above ground level. Rush cover showed an inconsistent trend, with use of both low (< 5%) cover and high (> 50%) cover occurring during elevated water levels (Figure 28).

Use of areas with higher litter cover also increased with higher water levels (Figure 29), again probably because of the addition of this structural component above ground level. The exception to this pattern is in use of areas with no litter cover. Water levels were generally higher when areas lacking litter were used by sparrows. We again believe that sparrows use other cover types such as sawgrass or emergent aquatic plants that do not readily accumulate litter in these cases. Use of open cover increased with decreasing water levels (Figure 30), but black-topped sedge cover showed an inconsistent pattern of use relative to water levels (Figure

31), with use of areas both lacking this cover type and with abundant sedge cover (25-50%) occurring during high water levels.

Sparrow distribution across the landscape

During the first field season, we detected a total of 45 Cape Sable seaside sparrows during all three surveys at 6 of the 8 study plots (Fletcher et al. 2000). The two plots where we did not locate sparrows during the surveys were Taylor Slough and Far South, and we do not have any information on the occupancy of these sites during the breeding season. Sparrows were observed in the vicinity of the Far South site, however, and one of the radio-marked sparrows traveled there earlier in the non-breeding season. We may have failed to locate sparrows at Far South during our surveys due to limited sampling effort (only 1 transect was sampled). We observed sparrows on all sites where they were known to occur during the breeding season.

During the second field season, we observed a total of 24 Cape Sable seaside sparrows at 16 of the 34 plots associated with the breeding season survey points (Table 6), although a sparrow was detected on one of the plots only after completion of the rope-dragging transect sampling. These results continue to suggest that sparrows do not change their distributions appreciably between the breeding and non-breeding seasons.

Comparison of the rope-dragging surveys to the 1999 breeding season sparrow surveys (Bass and Pimm 1999) revealed that sparrows occurred at all of the selected breeding season sample sites where we observed them during the non-breeding season. Of the 34 points that we visited during the non-breeding season of 1998-1999, 8 were not surveyed during the 1998 breeding season. We did not locate any sparrows at these points. For the remaining 26 points, our non-breeding season surveys located sparrows at 6 points where sparrows were recorded during breeding season surveys and failed to locate sparrows at 5 points where they had been recorded during the breeding season.

In 13 cases, breeding season and non-breeding season surveys were in concurrence. Eight of the concurring cases documented sparrow presence during both breeding and non-breeding seasons. It is difficult to evaluate apparent discrepancies in sparrow presence between the seasons, however, due to differences in survey methodology. A single survey relying primarily on auditory cues as is done in the population survey may fail to detect sparrows due to local habitat or weather conditions. Similarly, sparrows may be missed during the rope-dragging

surveys, or sparrows may be present just outside of the sample plot at the time of sampling. Because the majority of points were similar between the breeding and the non-breeding seasons with regards to either presence or absence of sparrows, however, we believe our results do not suggest a large-scale change in sparrow distribution between the breeding and non-breeding seasons.

Survival

Estimated from Telemetry

During the first field season, we documented 4 mortalities and censored 5 of the radio marked individuals. In contrast, we only recorded one mortality during the second field season, and this was a juvenile sparrow. We censored 11 individuals during the second field season. Most of the censored individuals were probably lost due to transmitter failure (see above).

The best model (based on AIC) that produced survival rate estimates for radio-marked sparrows was the reduced model (no effects of age or time), for both field seasons (Table 7). The weekly survival rate estimate (includes all individuals, $n = 19$ sparrows) for the 1997-1998 field season was $0.987 (\pm 0.009 \text{ SE}, 95\% \text{ CI} = 0.965 - 0.995)$. The weekly survival rate estimate for all sparrows ($n = 24$) during the 1998-1999 field season was $0.998 (\pm 0.002 \text{ SE}, 95\% \text{ CI} = 0.987 - 0.999)$, probably higher because we did not document any adult mortality during the second field season. Comparing longer-term survival rates between the two field seasons using a 31 week period (length of the 1997-1998 field season) indicate that a sparrow alive at the beginning of the 1997-1998 field season would have a probability of 0.67 of surviving to the end of the 31 week period. Using the weekly estimates for the 1998-1999 field season, a sparrow alive at the beginning of the 1998-1999 field season would have a probability of 0.94 of surviving to the end of a 31 week period. These results suggest that sparrow survival is highly variable among years.

Estimated from Resightings

The best CJS model (based on AIC) that produced survival rate estimates using resighting data from the second field season again was the reduced model (no effects of age or time, Table 8), and the model fit the data (Program RELEASE goodness of fit, $\chi^2=34.84$, $df = 56$, $P = 0.99$). As with the telemetry data, additional parameterization of CJS models produced higher AIC values, most likely as a result of our limited data set. Resighting probabilities varied

substantially, however (Figure 32), with the highest resighting probabilities occurring in June and early July, as expected, during the breeding season. This is consistent with previously reported behavioral patterns that improve the likelihood of observing banded sparrows (Dean and Morrison 1998, 2000). From the CJS model, weekly survival probability was 0.985 (+ 0.008 SE, 95% CI = 0.956-0.995, Table 8b), similar to weekly estimates produced from the telemetry data. Again for comparison purposes with the telemetry data, this resulted in a 31 week survival rate of 0.63.

Mortality factors

Four of the 5 mortality events that we recorded were depredations. Three appeared to be the result of avian predators. In these cases, we recovered remains of sparrows underneath exposed perches where raptors typically handle prey, and remains consisted of feathers plucked from the bird and larger bones that were stripped of flesh. These remains are consistent with depredation by a raptor.

In one case, as we radio-tracked a sparrow transmitter, we found that the signal was emanating from a cottonmouth near where the sparrow had last been seen. We collected and radiographed the cottonmouth and confirmed that the radio-marked sparrow had been consumed by the snake (Figure 33). We subsequently dissected the snake and removed the sparrow carcass for additional analyses (see above).

The final mortality that we recorded was an unexplained mortality that occurred during the first field season. We collected the carcass within 1 day of the mortality event and transported it for necropsy to the Department of Veterinary Medicine at the University of Florida, Gainesville. The ultimate cause of death could not be determined, but mild pulmonary edema was diagnosed. The cause of the pulmonary edema could not be determined, but it is unlikely that it was related to the transmitter or harness (M. Spalding, pers. comm.). Radio telemetry in this case may have allowed us to document a mortality that we would not have otherwise recorded.

Relationships to the Breeding Season, Chronology, and Behavior

We developed a chronology of the behavioral and environmental characteristics that we observed during our study periods (Figure 34), and these observations were relatively consistent among the two years. During both years of our study, we observed breeding activity through

July and into August. We initiated the first field season in late July 1997 at our HR study site and observed a few singing males still present on the area. While it was clear that the rate of singing and other territorial activities were reduced compared to the peak of the breeding season, all adult sparrows that we captured during July 1997 were reproductively active. Male sparrows had substantial cloacal protuberances, and females had distinct brood patches.

On 9 August 1997, we confirmed late breeding activity when we captured a juvenile Cape Sable seaside sparrow that had just left the nest and was not yet capable of sustained flight. This individual would have left the nest only 1-2 days at most, prior to capture. This observation confirmed that Cape Sable seaside sparrows are capable of breeding late into the summer.

During the second field season we again observed breeding behaviors in July and August and documented 9 nesting attempts by sparrows after June 1998, including 2 nest attempts by a radio-marked female. While many of the nests we observed this late in the breeding season were not successful, several did fledge young, and we additionally observed adults feeding young from nests that we did not find.

The initiation of molt is probably a good indicator of the end of breeding activity, although some adult sparrows may continue to feed young after they begin feather replacement. The high energetic costs of egg production and rearing young likely make it difficult to replace feathers and raise young simultaneously. We observed the first signs of molt in July of both years, although some sparrows that we captured had not initiated molt by early August. Molt peaks in September, with most individuals completing molt by the end of October.

Juvenile sparrows may initiate molt before adults. During the second field season, the first individuals that molted were juveniles. However, some juveniles also showed a protracted molt, and both adults and juveniles appeared to complete molt at approximately the same time.

Molt also coincided with marked changes in behavior of both adult and juvenile sparrows. During molt, sparrows became more solitary (especially juveniles), time spent perching visibly decreased, and vocalizations ceased. All sparrows also adopted centered movement patterns. By the end of molt, observations of social interactions were relatively unusual. Prior to our research, Balent et al. (1997) noted that sparrows were readily observable early in the non-breeding season and then became increasingly difficult to locate and observe beginning in October. These observations are consistent with resighting probabilities calculated in survival analyses (see above). We failed to detect a change in movement or distribution

patterns between times when sparrows were readily observable and when they were secretive, indicating that the apparent change is only a change in behavior.

During the non-breeding season in general, Cape Sable seaside sparrows were generally solitary, but we recorded numerous instances in which small aggregates of sparrows (2-3 individuals) were observed. While groups were generally composed of only a few sparrows, we observed group sizes of up to 26 individuals. In general, individuals within a group flew in the same direction when flushed, alighted within a few meters of one another and vocalized frequently. These aggregates usually included several juveniles and 1-3 adult sparrows. Both male and female adults were observed within these small flocks. Observations of banded sparrows within flocks indicated that membership in flocks changed regularly. Werner and Woolfenden (1983) also reported changing membership in flocks of juvenile and adult sparrows in the fall. We rarely observed groups of sparrows after the initiation of molt, and sparrows remained solitary until the initiation of territoriality in the spring.

We observed the first signs of territorial behavior in mid-January when we first heard males singing in our study sites. However, sparrows did not sing consistently until early to mid-February, when we observed the first song flights. Most of the sparrows that we observed engaging in territorial behaviors early in the breeding season were first-year birds, and many of these seemed to have been displaced later in the spring. Male sparrows that we captured early in the breeding season also did not have large cloacal protuberances. These two observations suggest that some of the early territorial activity may not indicate the initiation of breeding but may be a precursor to more aggressive territorial behavior.

Investigating Genetic Relationships

The taxonomic status of the seaside sparrow complex has been a subject of substantial speculation. The most revealing research on this subject was reported by Avise and Nelson (1989). These authors collected whole sparrows and extracted mitochondrial DNA to compare the matrilineal relatedness of the 9 recognized subspecies (8 now extant). At the time of the 1989 study, they were denied permission to collect Cape Sable seaside sparrows and consequently excluded this subspecies from their analysis.

Long-PCR successfully amplified mtDNA from the liver tissue of the sparrow removed from the snake and also from 4 blood samples. Digestion of the amplified DNA by the 18

restriction enzymes used in the original analyses (Avisé and Nelson 1989) resulted in 91 restriction fragments from the sparrow extracted from the snake but only partial (but still scorable) digestion profiles from the DNA extracted from blood samples. All scorable digestion patterns from all specimens were clearly consistent with membership of the Cape Sable seaside sparrow in the Atlantic, as opposed to the Gulf Coast, matrilineal clade of seaside sparrows (Nelson et al. 2000).

Diet

We obtained some information about the diet of Cape Sable seaside sparrows during the non-breeding season from fecal samples, however, these results should be interpreted with caution. Identifiable items that we observed in feces are not the only items consumed by the sparrows, and results are biased by the digestibility of different items. Thus, these results can be only interpreted as representing some unknown portion of the items that sparrows ingest during this portion of their life history. These data are still valuable, however, because the only other feasible means of obtaining information on non-breeding season diet is through exhaustive observation or by invasive means, both of which are not possible.

We collected 83 different fecal samples and treated each as an independent sample, despite the fact that some were collected from the same individuals on different occasions. We did not observe any identifiable fragments in 10 of the samples; these collections consisted of uric acid and fluid. In fact, most fecal samples included large quantities of uric acid, possibly indicating a protein-rich diet. The two most readily identifiable items that we regularly encountered in sparrow feces were shell fragments of snails and fragments of insect exoskeleton. Legs and various hard parts of small weevils were the most readily identifiable insect fragments.

Sixty-one percent of all samples contained snail shell fragments and 57% contained identifiable portions (heads or legs) of weevils. An additional 11% of samples contained various insect parts. Only 4% of samples contained seeds or seed coats suggesting that seeds do not comprise a large portion of the diet of the Cape Sable seaside sparrow. In contrast, seed coats were frequently and easily identified in feces of a congener, the Florida grasshopper sparrow, which is known to feed regularly on seeds during the non-breeding season (T. Dean, unpubl. data).

Parasites and Disease

We recorded ectoparasites on 21 Cape sable seaside sparrows. In 4 cases only wing mites were observed. In 19 cases chewing lice were observed, and both parasites were observed on 2 sparrows. We collected specimens of both parasites for identification but have not yet received results. D. Forrester recorded the presence of one species of mallophaga on a seaside sparrow in Florida (pers. comm.). Post and Enders (1970) also reported chewing lice on seaside sparrows in New York. Mites have not been recorded from seaside sparrows in Florida.

We most commonly located chewing lice on the sparrow's head and nape, with eggs deposited around the ears and on the throat. We generally observed chewing lice eggs in conjunction with several adult lice. We observed parasites on > 1 successive capture of 9 of the 19 sparrows that had lice, and in all of these cases, more parasites were observed on each subsequent capture. We observed the heaviest loads of chewing lice near the beginning of the breeding season, in March 1999. In the most heavily infested individual, we observed approximately 50 adult lice on the head and neck as well as approximately 60 eggs around the ears. We did observe some feather degradation on the heads of some sparrows but could not conclusively identify lice as the cause.

The second ectoparasite we observed was a type of mite that infested the flight feathers of sparrows near the feather shaft. Although not yet identified, these mites are likely detritivorous, feeding on particles trapped on the wing.

All 10 blood smears returned negative for hemoparasites and blood-borne pathogens (G. Foster, pers. comm.) and contained no evidence of parasites or disease.

DISCUSSION

Radio telemetry proved to be an excellent methodology for obtaining consistent information on Cape Sable seaside sparrows during the period of the year when they are otherwise nearly impossible to find and observe. While we can not conclude that transmitters do not affect sparrows in any way, we recorded no evidence of severe or chronic impact on sparrows, even in conjunction with changes in environmental conditions. The breadth and duration of information provided by radio telemetry allowed us to record more than just a snapshot of sparrows' behavior during the non-breeding season. It allowed regular, in-depth data recording on sparrow behaviors and interactions with their habitat and with each other over

several months each year, across a wide array of environmental conditions, during several physiological periods, and throughout large areas of the landscape.

Movements

Several patterns emerged regarding how sparrows use space. The distance that sparrows generally traveled and the areas that they regularly used were remarkably similar across individuals, even under varying environmental conditions over time and among sites. This lack of variation among individuals suggests a consistent habitat use strategy across genders and age classes. Cape Sable seaside sparrows are primarily sedentary, occupying home ranges that contain breeding season territories. Instead of moving among areas with varying habitat configurations as environmental conditions changed, they remained within the same general area and simply used micro-habitats with different structural characteristics.

Despite this predominantly sedentary pattern, sparrows are quite capable of traveling across extensive areas of contiguous prairie habitat. We regularly observed relatively long-distance movements by individuals (mostly juveniles) early in the second field season. Throughout our study periods, a few adults also moved relatively long distances and establish new home ranges some distances from previous home ranges. Juvenile sparrows adopted a nomadic lifestyle following independence during which time they apparently range widely and interact with many other juvenile and adult sparrows. We regularly observed juvenile sparrows moving in groups across the landscape. This period following independence when juvenile sparrows moved more widely than at other times probably represents dispersal from natal territories. The extent (timing and scope) of movements that we documented is generally larger than that reported by other authors (Lockwood et al. 1997, Werner and Woolfenden 1983, Pimm et al. 1997).

Traveling in groups may be a mechanism for successful colonization of unoccupied habitats because it overcomes the low likelihood of multiple dispersals to a particular unoccupied site. Additionally, flocking may protect individual juveniles from predators or from defensive territorial males, by overwhelming them.

Molt seemed to effectively terminate the dispersal period for juveniles, and following the initiation of molt, all sparrows showed a primarily sedentary pattern of behavior. Subsequent to

this behavioral change, most juvenile sparrows exclusively used areas similar in size to adult home ranges.

Juvenile sparrows are not the only individuals that travel long distances, however. We recorded long-distance movements by one adult female and recaptured a previously banded adult female over 1 km from a previously known territory. In these cases, movements from one home range to another were rather direct and lacked pattern, suggesting broad exploration. In all of these cases, sparrows again settled after several days and established a home range similar in size to the average sparrow home range.

Habitat selection

Our analyses examining habitat selection by Cape Sable seaside sparrows suggests that despite their generally sedentary nature, sparrows tend to occupy areas with a broad array of micro-habitat conditions that provide protection and food as water levels fluctuate by as much as to 15-60 cm during the non-breeding season. Unlike its more northern relatives, the Cape Sable seaside sparrow is required to endure elevated water levels for extended periods because water drains from the prairie marshes at a very slow rate. Considering the degree of variation in the marl prairie environments, local, small-scale variation in habitat may be the primary characteristic that sparrows select. Sparrows clearly used areas dominated by different vegetative species and with different habitat structures as water depth varied across the prairie. Use of different vegetative species and cover classes during high water levels seems related to the structural characteristics of the vegetation and its ability to support sparrows above the water level and to provide some degree of protection from predators. Under high water conditions, cover may be a limiting resource for sparrows, although sparrows may become more vulnerable as their options for escape become limited (see below).

At the landscape scale, some degree of structural variation seems important. The one consistent pattern noted was the avoidance of forested areas, and this is consistent with reports of other authors (Lockwood et al. 1997, Werner and Woolfenden 1983). Sparrows never approached continuous or extensive forested areas, and these features seemed to effectively deflect sparrows that were traveling toward them. These observations combined with movement data obtained from telemetry suggest that it is unlikely that sparrows readily move across forested areas to potentially available habitats.

Survival

The primary limitation of the survival analyses we conducted was sample size. Improved sample sizes would probably have allowed additional parameterization and more accurate assessment of any effects of age, gender, or time on both survival and resighting probabilities. In all likelihood, survival and resighting probabilities are both affected by such variables, but with our sample size during both field seasons, the data we obtained only supported the reduced models. We also do not provide annual survival rate estimates, although this has been done by other investigators, because we only conducted our research during the non-breeding season and we do not have any information on how survival rates may differ during the breeding season. As such, we do not feel that using our weekly survival estimates derived during the non-breeding season to extrapolate to annual rates is appropriate.

Examination of our survival rate estimates and those provided by other investigators (Table 9) suggest that survival is quite variable for Cape Sable seaside sparrows. Published annual adult survival rates range from 0.50 - 0.90 (Kushlan and Bass 1983, Pimm et al. 1999, Werner and Woolfenden 1983). Our estimated weekly survival rates generally support this range as well as an average annual survival rate well above 50%. It is difficult to compare these rates among studies, however, because of reasons mentioned above and because the methodology used by other investigators to derive their estimates is not clear.

It is reasonable to suspect, however, that the dramatic variations in hydrological and other environmental conditions within the Cape Sable seaside sparrow's range may result in high variability in survival rates. Seasonal and annual variation in water levels result in changes in sparrow behavior and microhabitat selection and may produce similar changes in behavior of other species that inhabit the prairies, including common sparrow predators. Telemetry results indicate that predation seems to be a major mortality factor for adult and independent juvenile Cape Sable seaside sparrows.

Understanding hydrology

To this point, all aspects of the sparrow's ecology has been related to water depths, and this pattern is probably an accurate assessment and is undoubtedly inherent in studies of most organisms inhabiting the Everglades system. We only conducted limited hydrological monitoring at our sites but quickly discovered the complexity of the hydrology within the marl

prairies. Past research (Nott et al. 1998, Lockwood et al. 1997) has investigated relationships between hydrologic conditions and sparrow nesting and distribution using data at the landscape level. However, complementing that approach, our data suggest that an accurate understanding of changes in water levels at a small scale may also be required to accurately evaluate relationships between events in the sparrow's life history and hydrology in the prairies.

At first glance, the marl prairies within the Everglades system appear to be a vast, flat expanse with little topographic relief. However, there actually exists a large degree of local variation in topography and elevation, and this variation results in varying hydroperiod and depth of inundation at a very small scale. To evaluate fully the effects of water depth in an area on sparrow habitat selection and behavior, information is required on the variation in elevation, and not merely the average. We conservatively recorded 20 - 30 cm of variation in elevation across our 2 study sites, providing a wide variety of micro-habitat conditions over space and time. The Everglades system is not closed, and water flows broadly across the landscape. Consequently, the rate of change in water depth is not uniform at different points, or over time at the same points. The slope of the local terrain, the relative elevation of areas, and the density of vegetation all can effect differences in the relative rate of drying between sites. When local differences in rainfall are introduced into the equation, the difficulty of accurately predicting depth of inundation at any point on the landscape becomes overwhelming, and regular, on-site measurements are required to evaluate hydrologic effects accurately.

A number of models have been created to represent the hydrology of the Everglades system, but because of the large extent of the Everglades, most models represent the system with a minimum spatial unit of 1-2 km². While the hydrologic characteristics that the best of these models indicate for such an area may be appropriate at that scale, they do not address the degree of variation within the area at the level of importance to the Cape Sable seaside sparrow. Any degree of variation in topography and hydroperiod within a much smaller area may act to buffer sparrows from the severe effects of flooding. Additional research should be conducted at multiple scales to determine sparrow response to varying hydrologic conditions.

CONCLUSIONS

- 1) We captured and radio-marked 45 Cape Sable seaside sparrows and successfully recaptured most individuals several times to replace radio transmitters for long-term data collection. Radio telemetry was an effective method for obtaining detailed, long-term, individual-based data.
- 2) Monitoring of several physiological condition indicators and behaviors provided no evidence of detrimental effects of transmitters or the transmitter attachment on the sparrows.
- 3) Both adult and juvenile sparrows are generally sedentary during the non-breeding season following molt. Individuals maintained home ranges generally larger than breeding season territories. Some individuals moved considerable distances between consecutive locations but stayed overall within the study area (marl prairie). Patterns of home range size and movements of individuals did not differ substantially between genders or between the two study sites or years.
- 4) Juvenile sparrows apparently travel widely across the landscape shortly following independence but generally become sedentary with the onset of molt, similar to adults.
- 5) Some sparrows made relatively long distance movements (1-7 km) suggesting this capability at the population level. However, sparrows consistently ceased these long-distance movements at the margins of the prairie habitat and never traveled through forested habitat.
- 6) Sparrows apparently are entirely dependent on the open prairie habitats. None of our radio-marked individuals ever departed from prairie habitats at any time during the non-breeding season. They did not avoid isolated tree islands within an open matrix, but did apparently do avoid large tree islands, tree lines, and forested areas with higher tree density. Sparrows tended not to perch high (above 1 m) in woody vegetation.
- 7) Considerable variation existed between the study sites in terms of vegetation characteristics and water levels. Regular measurement of water levels indicated substantially different hydrology at micro-sites both within and between study areas. Fine-scale variation in hydroperiod across our sites may allow some sparrows to breed late in the breeding season despite high average water levels.
- 8) Logistic regression models indicated that none of our measured habitat characteristics was consistently selected on our study sites. Sparrows may select some of these characteristics but the direction of selectivity toward certain variables was not consistent. Model results

suggest that sparrows used different vegetation types in different proportions under different hydrologic conditions. They used areas with higher sawgrass cover under wetter conditions and areas with higher *Schizocyrium* cover under dryer conditions. These results illustrate the importance of the structural characteristics of particular micro-habitats during different levels of inundation of the prairies.

- 9) We documented 5 mortalities of sparrows during our study. Three were due to predation, we suspect by aerial predators, one was an unexplained mortality, and one resulted from predation by a cottonmouth. Weekly survival rates estimated using telemetry and resighting data ranged from 0.985 to 0.998. While these rates suggest longer-term estimates of survival that are generally consistent with other published rates for this sparrow, survival rates for the Cape Sable seaside sparrow clearly vary considerably from year to year. Larger sample sizes are needed to test confidently for effects of age, gender, or time on survival rates of the Cape Sable seaside sparrow.
- 10) Surveys of potential sparrow habitat from November through February did not provide evidence of notable change in distribution of sparrows from the breeding season. Rope-dragging transects are effective in determining sparrow occurrence in prairie habitats.
- 11) From August through October, sparrows are relatively vocal and gregarious, improving their detectability. By late October, however, sparrows had notably changed behaviors. From November through January, sparrows were more solitary and secretive. We suggest that gregariousness in the early fall may be a mechanism to reduce individual predation while sparrows are molting and raptors are migrating through the area. We observed territorial behaviors as early as mid-January, despite the fact that both study sites were still completely inundated, yet some sparrows captured in the end of February lacked physiological evidence of reproductive activity.
- 12) Genetic analysis indicated that the Cape Sable seaside sparrow is a member of the Atlantic matrilineal clade.
- 13) Analysis of sparrow feces provided support for the hypothesis that Cape Sable seaside sparrows remain insectivorous throughout the year. Snail shells, weevil body parts, and parts of insect exoskeletons were commonly observed in fecal samples.

- 14) Parasite and disease screenings revealed regular occurrences of moderate loads of chewing lice and irregular occurrence of mites on sparrows. We detected no evidence of disease or hemoparasitism from a small sample of blood smears.

SUGGESTIONS FOR FURTHER RESEARCH AND IMPLICATIONS OF THESE RESULTS FOR SPARROW MANAGEMENT AND RECOVERY

While radio telemetry proved to be an effective method for obtaining detailed, long-term data on individual Cape Sable seaside sparrows during the non-breeding season, fieldwork was exceptionally difficult, and our sample size was definitely limited by the number of individuals that we could track. Additional such research conducted during the non-breeding season would indeed improve confidence in our conclusions because sample size would be increased and because we would learn more about the variation in patterns and parameters that we observed and calculated. However, the next level of questions pertinent to recovery of the Cape Sable seaside sparrow involve determining sparrow responses to changes in water levels or habitats at the scale of populations (for example, across the entire range of Population B) or landscapes (across the entire range of the subspecies). Therefore, we believe that further research conducted on Cape Sable seaside sparrows during the non-breeding season would best be approached from this larger scale perspective rather than continuing with individual telemetry work. Experiments conducted at the landscape level, such as habitat manipulations through fire or by altering water flows (timing and scope) would likely provide additional useful information for recovery planning. Such experiments, perhaps conducted in conjunction with radio telemetry, would provide useful answers to questions about how habitat management affects sparrows during the non-breeding season.

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Table 1. Cape Sable seaside sparrows that received transmitters and summary of monitoring duration and outcome.

Field season	Bird ID	Age	Sex	Earliest location	Latest location	Number of locations	Final outcome	Average distance between locations
1	733	A	F	11/01/97	12/24/98	96	removed	163.18
1	742	A	F	07/26/97	08/14/97	24	failed	167.31
1	843	A	F	08/10/97	02/27/98	175	removed	140.71
1	994	A	F	09/05/97	02/27/98	154	removed	156.77
1	442	A	M	08/09/97	12/11/97	115	predated	137.34
1	494	A	M	07/26/97	02/26/98	191	removed	192.05
1	545	A	M	07/26/97	07/26/97	3	death	
1	593	A	M	11/12/97	02/26/98	85	removed	120.61
1	892	A	M	08/09/97	02/27/98	175	removed	138.01
1	974	A	M	09/20/97	02/26/98	137	removed	139.53
1	1092	A	M	08/10/97	11/10/97	88	failed	152.04
1	1143	A	M	09/05/97		0	dropped	
1	544	U	U	11/11/97	02/26/98	88	removed	160.51
1	581	U	U	11/12/97	12/09/97	24	failed	123.31
1	753	U	U	11/01/97	12/03/97	29	removed	116.02
1	793	U	U	09/04/97	12/02/97	58	failed	253.04
1	942	U	U	09/04/97	02/27/98	154	removed	148.76
1	1032	U	U	11/20/97	02/21/98	76	predated	154.29
1	1042	U	U	08/22/97	10/01/97	40	predated	142.50
1	1093	U	U	11/11/97	11/12/97	2	dropped	
2	533	A	F	09/08/98	03/02/99	145	removed	161.45
2	753	A	F	06/16/98	03/03/99	224	removed	130.45
2	5003	A	F	06/21/98	03/01/99	218	removed	145.48
2	5102	A	F	07/23/98	02/28/99	112	removed	242.07
2	5132	A	F	07/20/98	03/02/99	194	removed	126.47
2	503	A	M	07/10/98	08/22/98	37	failed	226.41
2	602	A	M	06/21/98	03/02/99	160	removed	142.63
2	853	A	M	06/18/98	03/03/99	216	removed	154.15
2	952	A	M	07/10/98	07/20/98	10	failed	128.20
2	553	J	U	08/28/98	01/19/99	122	failed	192.84
2	694	J	U	11/09/98	03/02/99	101	removed	131.64
2	733	J	U	09/22/98	09/22/98	0	dropped	
2	784	J	U	09/21/98	01/24/99	96	failed	135.48
2	802	J	U	06/16/98	09/19/98	48	failed	277.13
2	832	J	U	12/12/98	03/02/99	68	removed	123.83
2	872	J	U	09/01/98	12/05/98	85	failed	153.37
2	902	J	U	08/11/98	03/02/99	181	removed	151.06
2	922	J	U	12/05/98	12/13/98	10	failed	92.88
2	5041	J	U	08/13/98	09/23/98	34	failed	170.49
2	5053	J	U	01/02/99	03/05/99	52	removed	248.80
2	5082	J	U	06/22/98	01/29/99	185	failed	310.55
2	5092	J	U	07/24/98	03/01/99	194	removed	218.35
2	5143	J	U	12/16/98	03/05/99	70	removed	116.30
2	5143A	J	U	06/22/98	01/25/99	110	failed	300.86
2	553A	J	U	06/21/98	06/21/98	1	predated	

TABLE 2. Home range characteristics for radio-marked Cape Sable seaside sparrows, 1997-1999.

Field Season	Bird ID	Age	Sex	Number of locations	Home range size	Number of ranges
1	733	A	F	96	11.55	1
1	742	A	F	24	10.90	1
1	843	A	F	175	13.74	1
1	994	A	F	154	18.4	1
1	442	A	M	115	9.36	1
1	494	A	M	191	29.35	1
1	545	A	M	3		
1	593	A	M	85	6.58	1
1	892	A	M	175	11.19	1
1	974	A	M	137	15.64	1
1	1092	A	M	88	13.61	1
1	1143	A	M	0		
1	544	U	U	42	26.42	2
1	581	U	U	24	8.26	1
1	753	U	U	29	6.6	1
1	793	U	U	58	11.43	1
1	942	U	U	154	17.81	1
1	1032	U	U	76	10.05	1
1	1042	U	U	40	13.53	1
1	1093	U	U	2		
2	533	A	F	145	55.46	3
2	753	A	F	224	8.91	1
2	5003	A	F	218	11.5	1
2	5102	A	F	112	12	1
2	5132	A	F	194	8.55	1
2	503	A	M	37	21.87	2
2	602	A	M	160	7.2	1
2	853	A	M	216	16.72	1
2	952	A	M	10		
2	553	J	U	122	24.81	2
2	694	J	U	101	10.46	1
2	733	J	U	0		
2	784	J	U	96	22.76	2
2	802	J	U	48	26.73	1
2	832	J	U	68	5.687	1
2	872	J	U	85	13.21	1
2	902	J	U	181	8.4	1
2	922	J	U	10		
2	5041	J	U	34	11.57	1
2	5053	J	U	52	25.23	1
2	5082	J	U	185	46.59	2
2	5092	J	U	194	25.35	1
2	5143	J	U	70	6.27	1
2	5143A	J	U	110	44.66	2
2	553A	J	U	1		

Table 3. Vegetation sampling effort at sparrow locations and random points, 1997-1999

Study site	Random points		Sparrow locations	
	1997	1998	1997	1998
EI	383	326	583	420
HR	17	550	866	613
Off-plot	504	184	25	103
TOTAL	904	1060	1474	1136

Table 4. Logistic regression models by site and year. Variables in bold were included in final parsimonious logistic regression models

Variable	ODDS RATIO (likelihood of association with sparrow location)			
	1997-1998 season		1998-1999 season	
	HR site	EI site	HR site	EI site
In clump?	4.53	1.55	1.09	5.30
Distance to nearest clump	1.00	1.02	0.99	1.03
Effective vegetation height	1.01	1.04	1.01	1.00
Maximum vegetation height	1.00	1.01	1.00	1.01
Water depth at location	1.00	0.98	1.02	0.96
Average water depth at site	1.06	0.99	0.97	1.03
Standard error of water depths at site	0.80	1.11	1.03	0.84
Soil depth at location	1.01	1.00	1.01	1.01
Average soil depth at site	0.99	0.95	1.02	1.01
Standard error of soil depths at site	1.00	1.07	0.93	0.93
Schizocyrium cover 0-5%	2.74	0.48	1.09	1.06
Schizocyrium cover 5-25%	4.17	0.66	1.11	1.26
Schizocyrium cover 25-50%	8.23	0.76	0.93	2.14
Sawgrass cover 0-5%	0.89	0.79	1.18	1.11
Sawgrass cover 5-25%	0.88	0.77	1.36	1.07
Sawgrass cover 25-50%	0.82	0.51	0.88	1.52
Sawgrass cover 50-75%	1.94	0.58	2.40	3.64
Litter cover 0-5%	0.84	0.65	5.98	0.50
Litter cover 5-25%	0.50	0.45	4.52	0.50
Litter cover 25-50%	0.63	0.33	4.92	0.55
Litter cover 50-75%	0.66	0.38	5.09	0.83
Litter cover 75-95%	0.58	0.20	5.58	3.40
Open cover 0-5%	0.84	2.11	0.66	2.08
Open cover 5-25%	0.76	2.32	0.82	2.83
Open cover 25-50%	0.62	2.49	0.95	6.89
Open cover 50-75%	0.51	0.92	1.15	12.85
Open cover 75-95%	0.18	0.37	0.37	14.09
Rush cover 0-5%	0.36	1.52	1.12	1.91
Rush cover 5-25%	0.36	1.06	1.04	2.18
Rush cover 25-50%	0.49	1.28	0.99	15.28
Black-topped sedge cover 0-5%			2.60	1.03
Black-topped sedge cover 5-25%			1.18	2.36
Black-topped sedge cover 25-50%			1.40	3.00
Discrimination (Area under ROC curve)	0.69	0.67	0.60	0.58
Hosmer Lemeshow goodness of fit statistic	6.773 p = 0.561	9.804 p = 0.279	7.01 p = 0.535	8.271 p = 0.407

Table 5. Statistical results comparing sparrow use of various vegetation cover types and structural characteristics relative to depth of inundation

Variable	Test statistic	statistic	df	probability
Open cover	Kruskal-Wallis AOV	61.915	5	0.00000
Black-topped sedge cover	Kruskal-Wallis AOV	99.71	3	0.00000
Litter cover	Kruskal-Wallis AOV	81.315	3	0.00000
Sawgrass cover	Kruskal-Wallis AOV	91.512	4	0.00000
Schizocyrium cover	Kruskal-Wallis AOV	116.505	3	0.00000
Rush cover	Kruskal-Wallis AOV	98.33	3	0.00000
In clump?	Mann-Whitney U	3.189	1	0.00000
Effective height	linear regression	$28.07+(0.817804*x)$		0.00000
Maximum height	linear regression	$98.256+(1.92*depth)$		0.00000
Distance to clump	linear regression	NA		0.87696

Table 6. Sparrow occurrence at breeding season survey points during non-breeding season surveys, and 1999 breeding season survey results.

Survey Point	Sparrows recorded during non-breeding season surveys	Number of sparrows recorded during 1999 breeding season surveys ¹	Discrepancies ²
Mahogany Hammock 11	0	0	
Mahogany Hammock 19	1	1	
Mahogany Hammock 21	2	2	
Mahogany Hammock 25	0	1	-
Mahogany Hammock 27	0	0	
Mahogany Hammock 29	1	0	+
Mahogany Hammock 36	0	1	-
Mahogany Hammock 38	0	2	-
Mahogany Hammock 39	1	1	
Mahogany Hammock 41	0	x	NA
Mahogany Hammock 48	2	2	
Mahogany Hammock 56	5	0	+
Mahogany Hammock 60	0	0	
Mahogany Hammock 63	2	0	
Mahogany Hammock 75	0	1	-
Mahogany Hammock 76	0	1	-
Pahayokee 34	0	x	NA
Pahayokee 35	0	x	NA
Pahayokee 42	0	0	
Taylor Slough 09	1	0	+
Taylor Slough 10	0	0	
Taylor Slough 16	2	1	
Taylor Slough 17	1	0	+
Taylor Slough 20	0	x	NA
Taylor Slough 24	0	x	NA
Taylor Slough 28	3	3	
Taylor Slough 35	0	x	NA
Taylor Slough 42	1	1	
Taylor Slough 50	0	x	NA
Taylor Slough 53	0	0	
Taylor Slough 56	0	4	
Taylor Slough 58	1	0	+
Taylor Slough 64	1	3	
Taylor Slough 89	0	x	NA
TOTAL	24	24	

¹ An x indicates that the point was not surveyed during the 1999 breeding season.

² A "+" indicates that sparrows were found during the non-breeding season but not during the breeding season, and a "-" indicates that sparrows were not found during the non-breeding season surveys but were found during the breeding season. Blank cells indicate concurrence between survey results.

Table 7. Best known-fate models for estimating survival parameters developed using location data from radio marked Cape Sable seaside sparrows.

1997 – 1998 field season				
Model	AIC	AIC Weight	No. Parameters	Deviance
Reduced model (S)	44.45	0.679	1	22.28
1998 – 1999 field season				
Model	AIC	AIC Weight	No. Parameters	Deviance
Reduced model (S)	16.61	1.000	1	10.11

Table 8. Best CJS model for estimating survival parameters developed using resighting data from banded-only Cape Sable seaside sparrows.

1998 – 1999 field season				
Model	AIC	AIC Weight	No. Parameters	Deviance
$\phi(.)p(t)$	16.61	1.000	1	10.11

Table 9. Comparison of survival rate estimates for Cape Sable seaside sparrows from various sources. ND = no data.

Source	Weekly	Annual
Radio-telemetry data (this study)		
1997 – 1998	0.987	-
1998 – 1999	0.998	-
Resighting data (this study)		
1998 – 1999	0.985	-
Lockwood et al. (2000)	ND	0.66
Pimm et al. (1997)	ND	0.50
Werner and Woolfenden (1983)	ND	0.90
Kushlan et al. (1982)	ND	0.90 (adults)
Kushlan et al. (1982)	ND	0.50-0.75 (juvenile)
Dean and Morrison (1998)	0.985	-

FIGURE 1. Study areas for the Cape Sable seaside sparrow non-breeding season telemetry project. Enlarged section is the southern tip of mainland peninsular Florida.

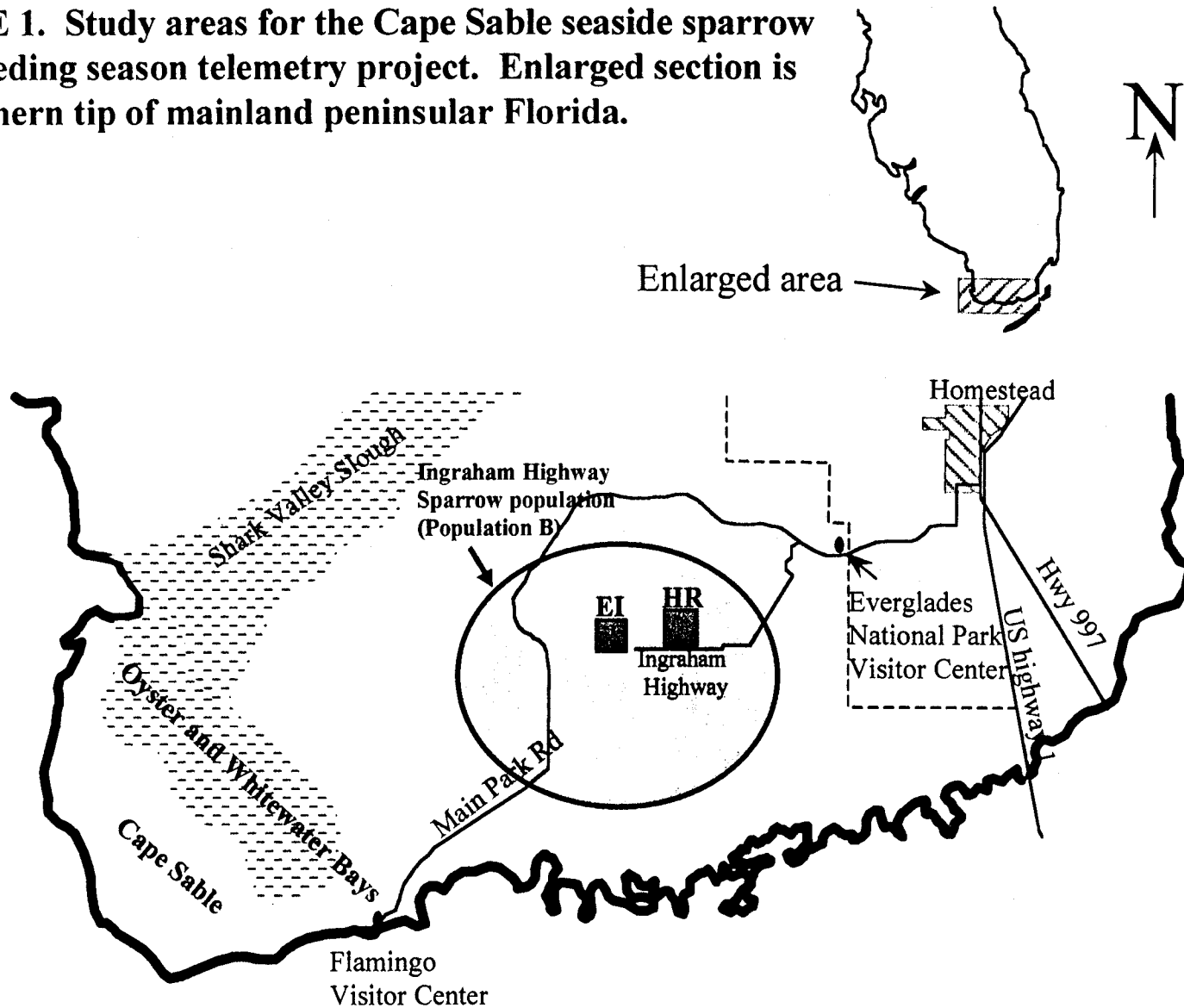


FIGURE 2. Study sites for determining landscape-level
Cape Sable seaside sparrow occurrence and density

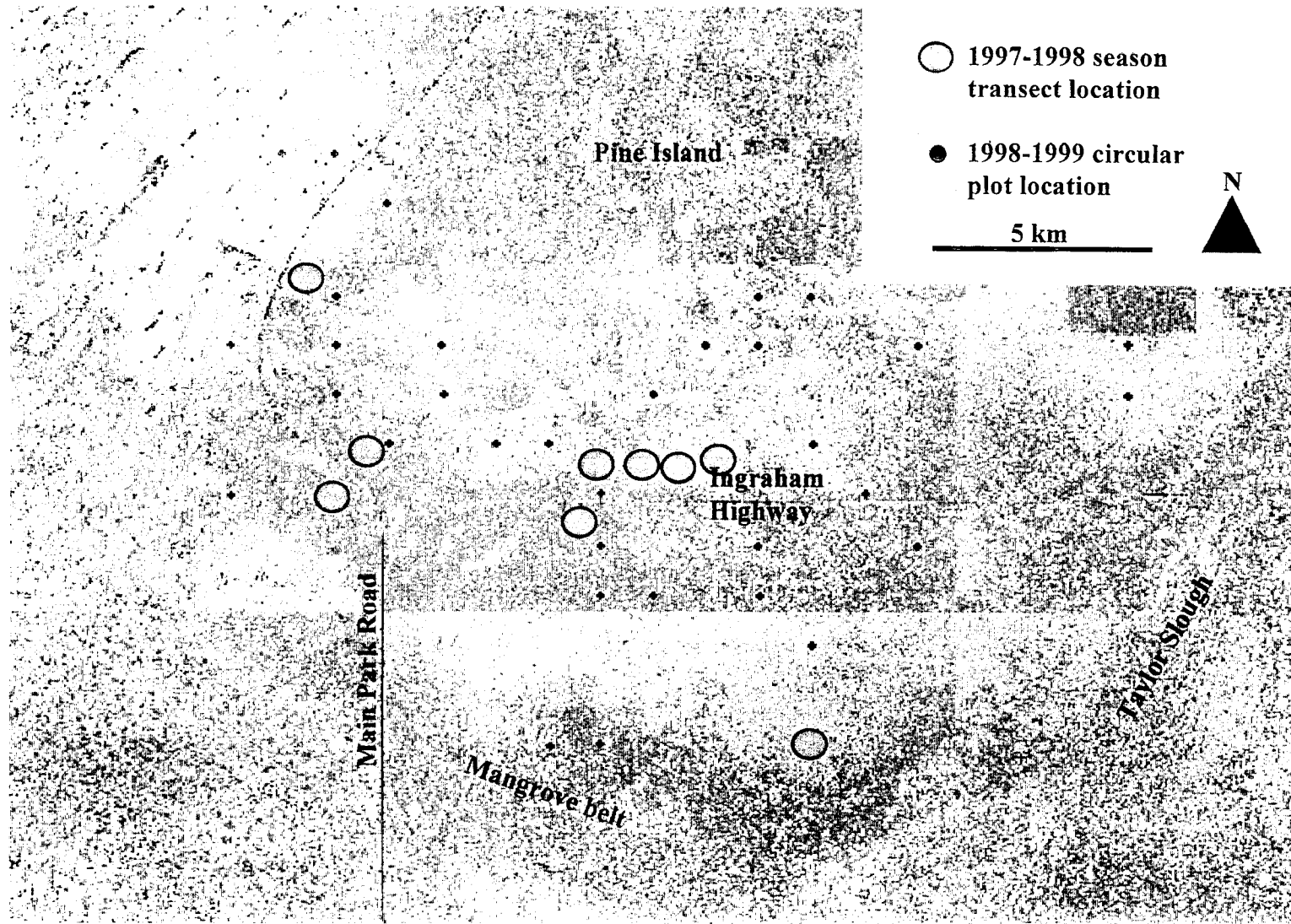


FIGURE 3. Reference posts for recording sparrow locations on study areas and sites where sparrows settled off of study plots

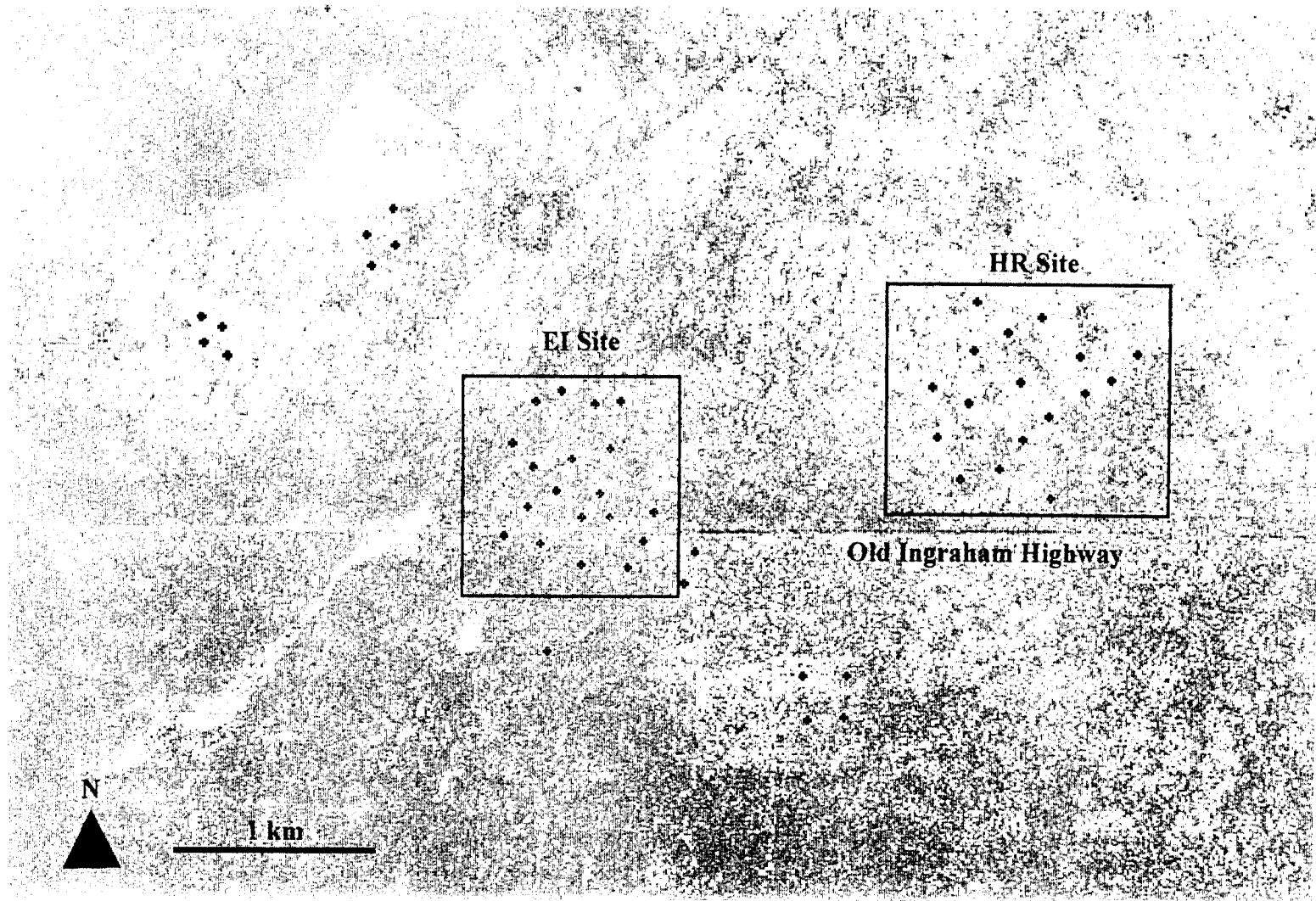


FIGURE 4. Mean weight over time for radio-marked sparrows and sparrows without transmitters, 1997-1999

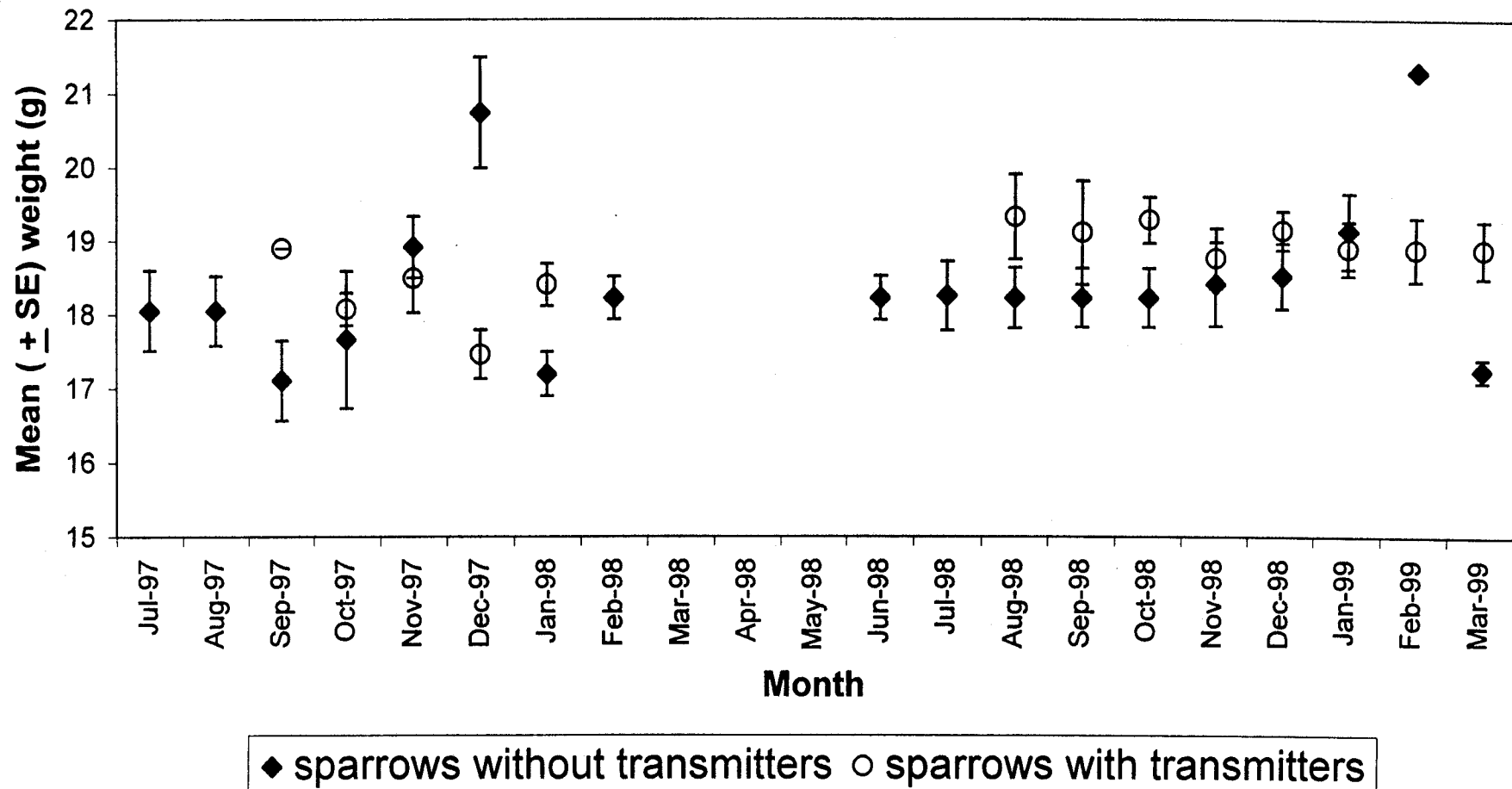


FIGURE 5. Fat scores over time for radio-marked sparrows and sparrows without radio transmitters, 1997-1999

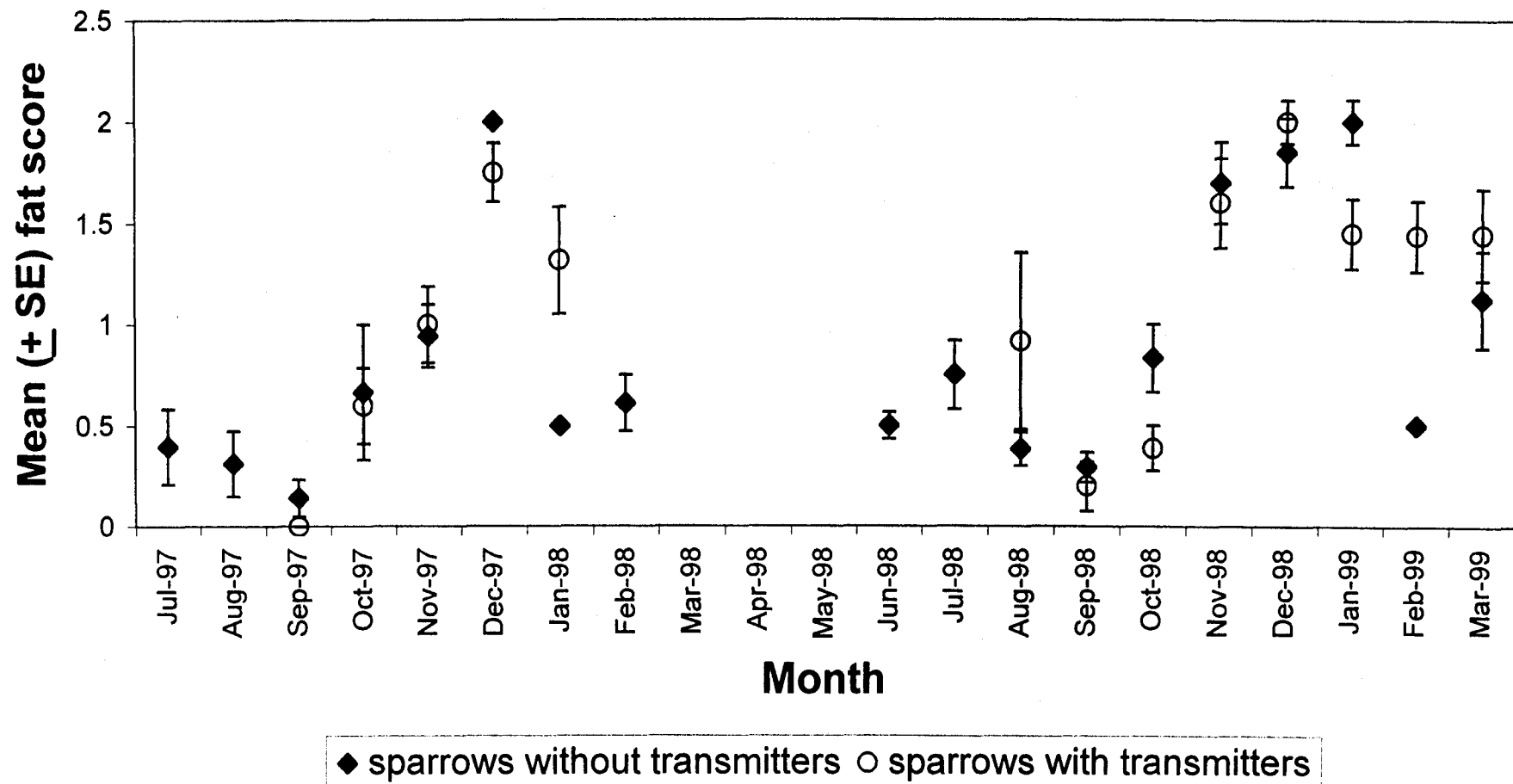


FIGURE 6. Mean number of molting (partial) flight feathers over time for radio-marked sparrows and sparrows without transmitters, 1997-1999

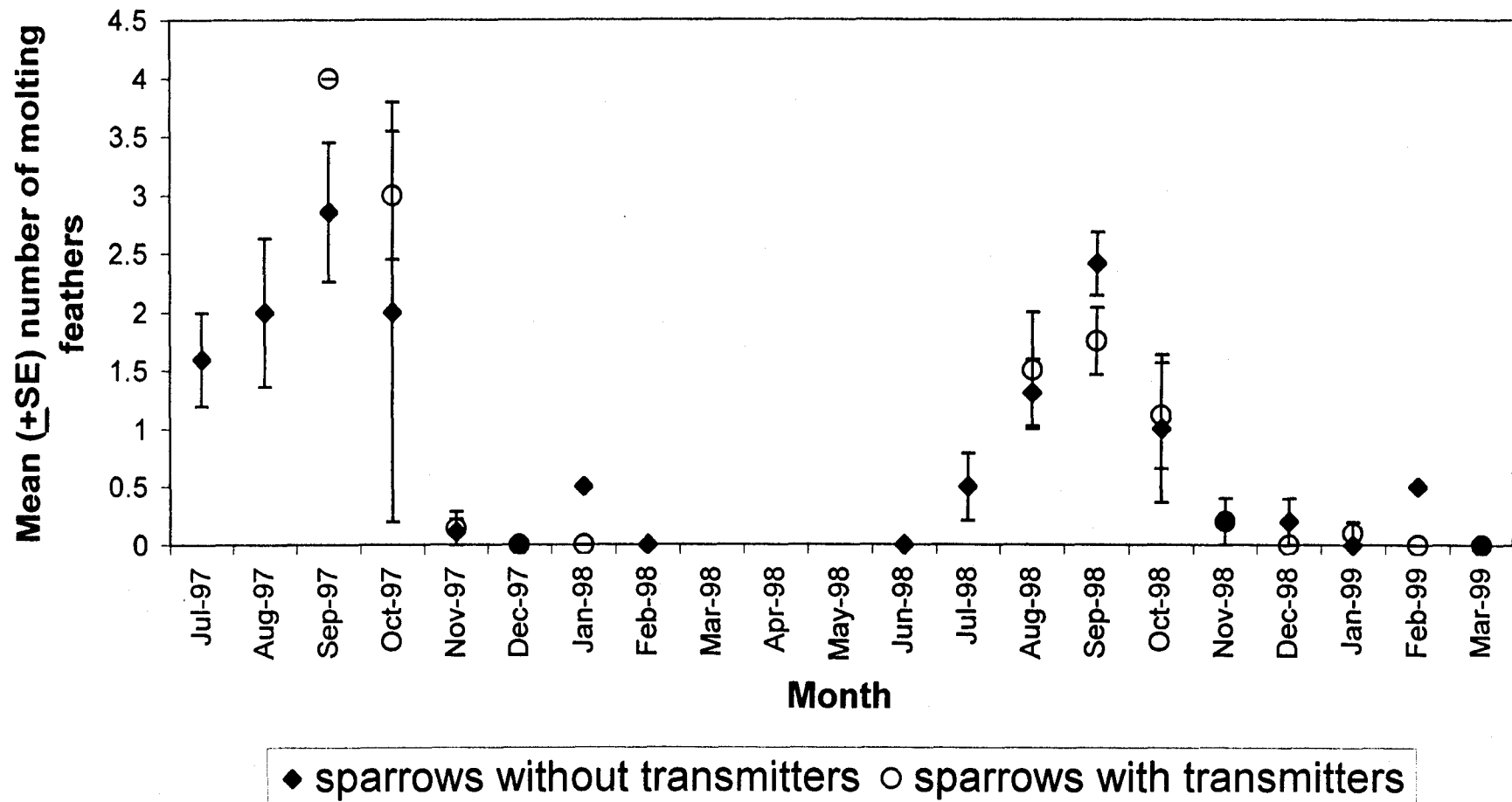


FIGURE 7. Change in weight and fat scores of radio-marked Cape Sable seaside sparrows plotted against relative transmitter weight, 1997-1999

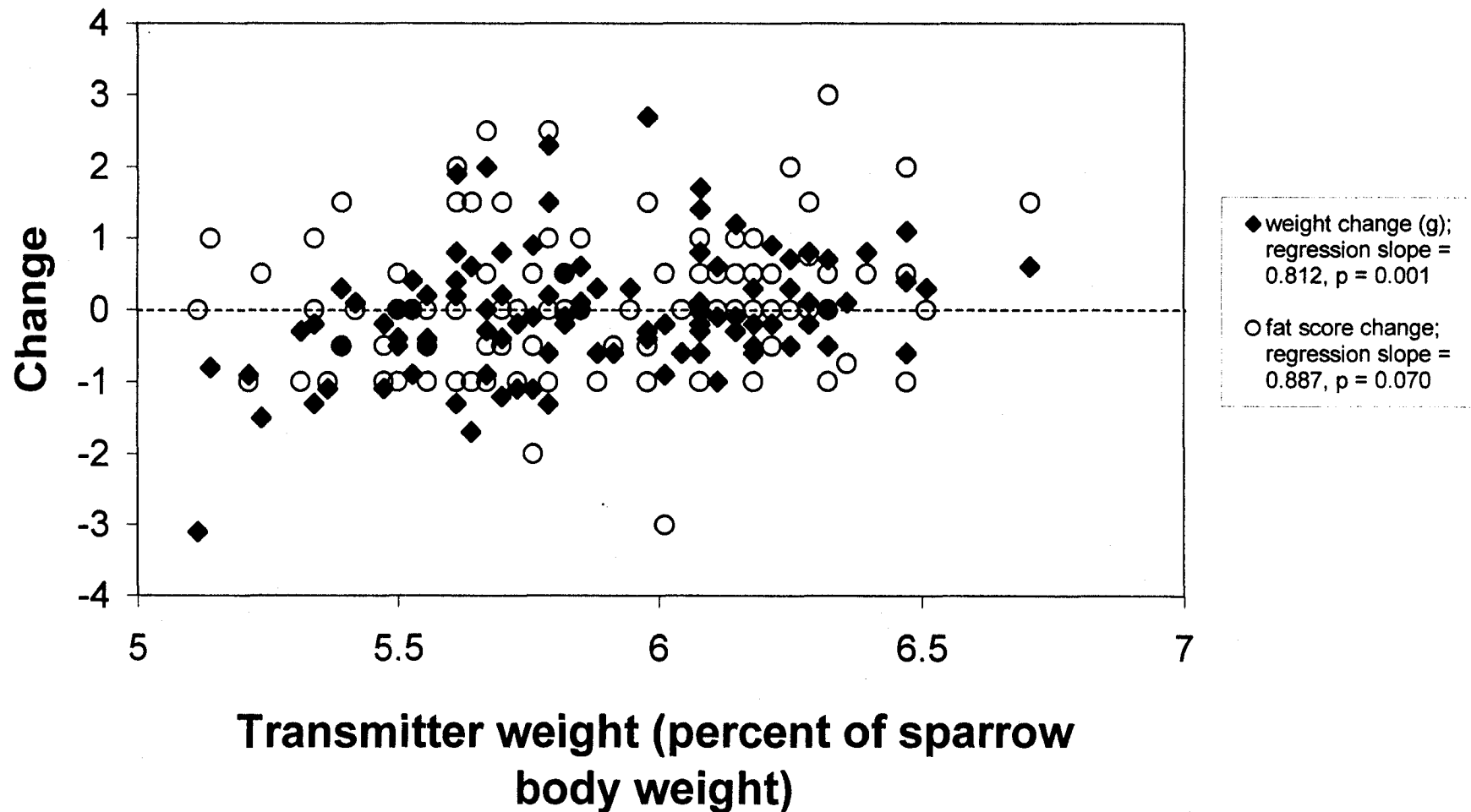


**FIGURE 8. Distribution of distances between locations
for radio-marked Cape Sable seaside sparrows,
1997-1999**

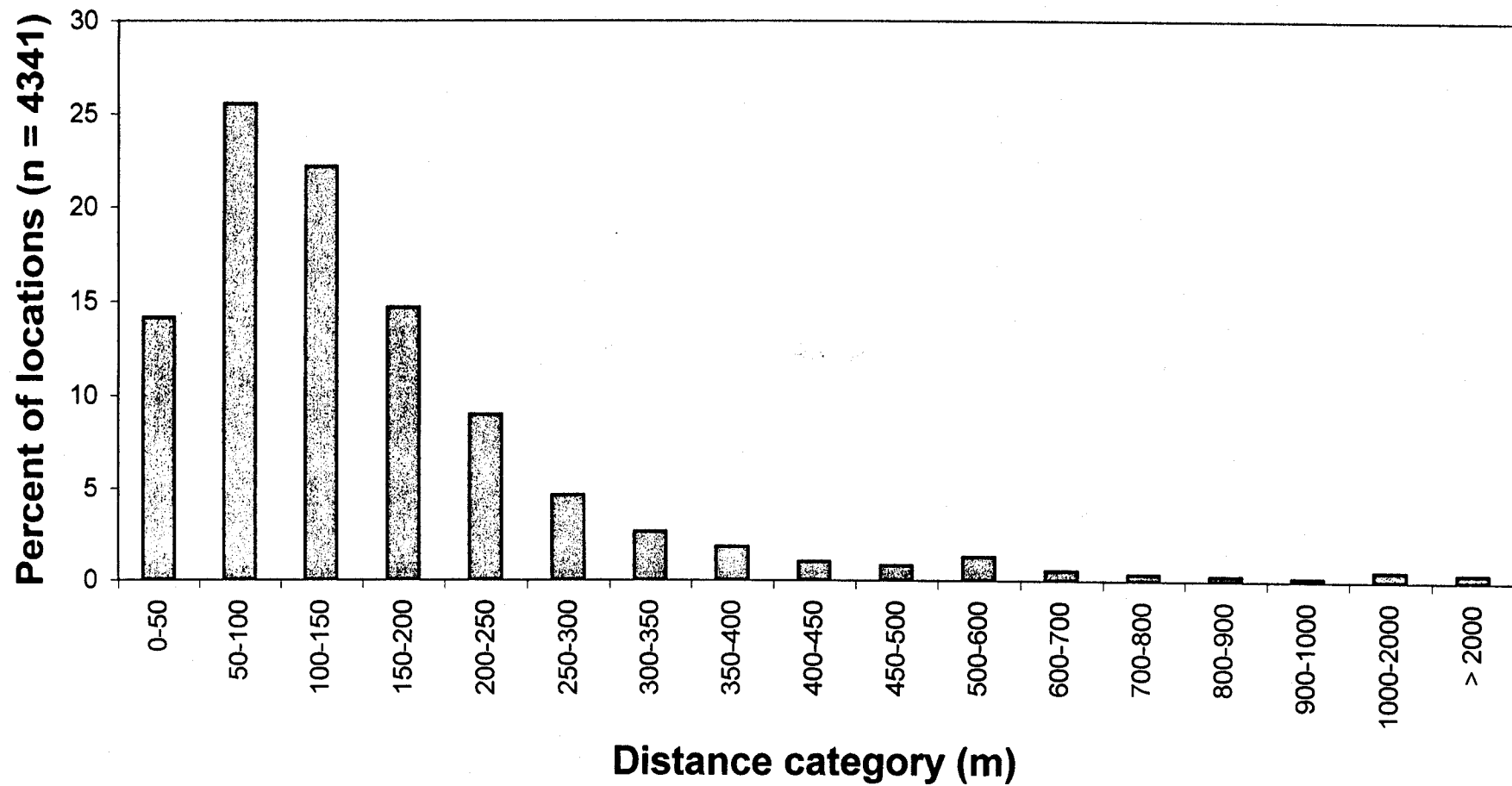


FIGURE 10. Distribution of distances between consecutive locations for adult and juvenile sparrows, 1997-1999

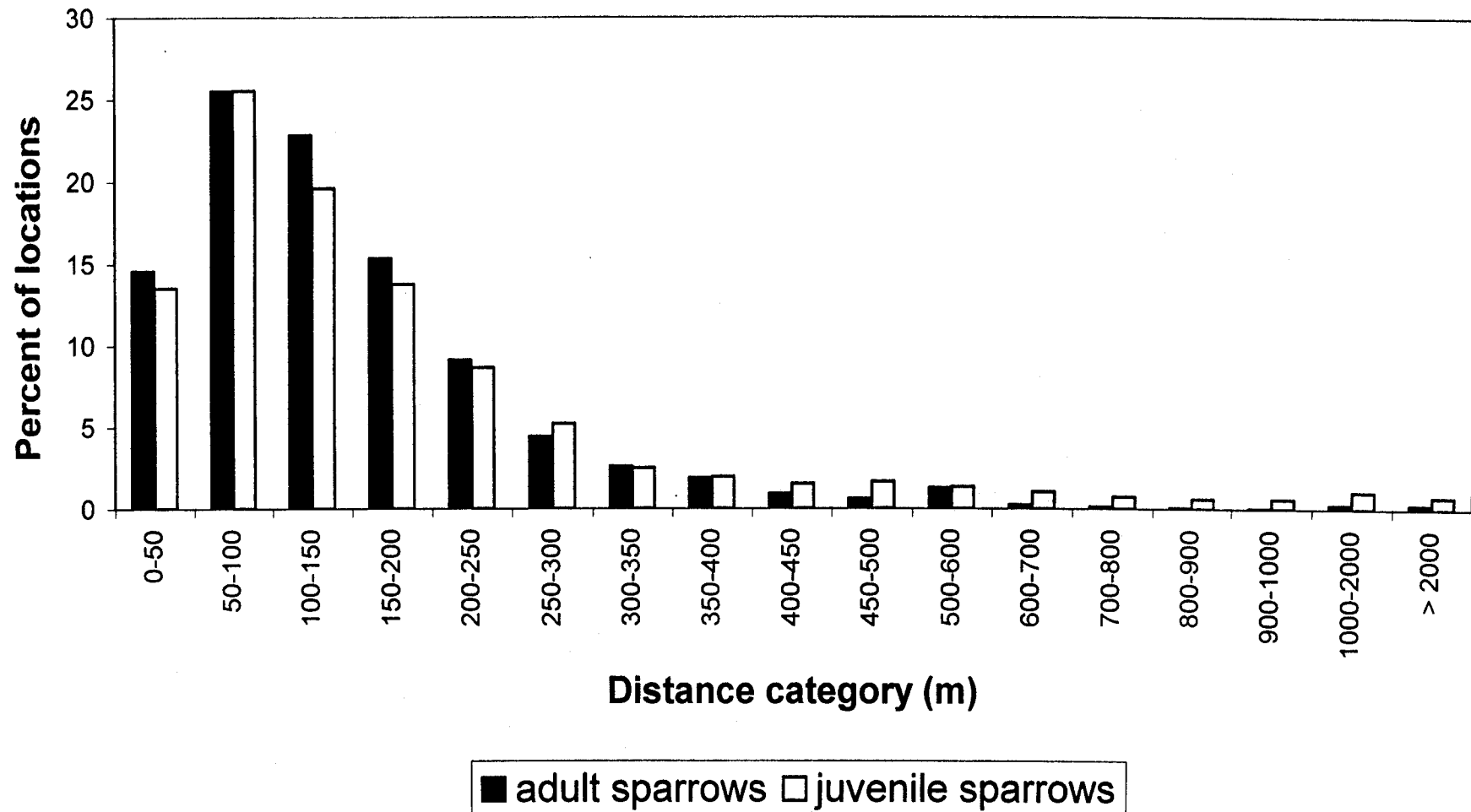


FIGURE 11. Occurrence of movements in the upper tail of the movement distribution over time for radio-marked juvenile Cape Sable seaside sparrows

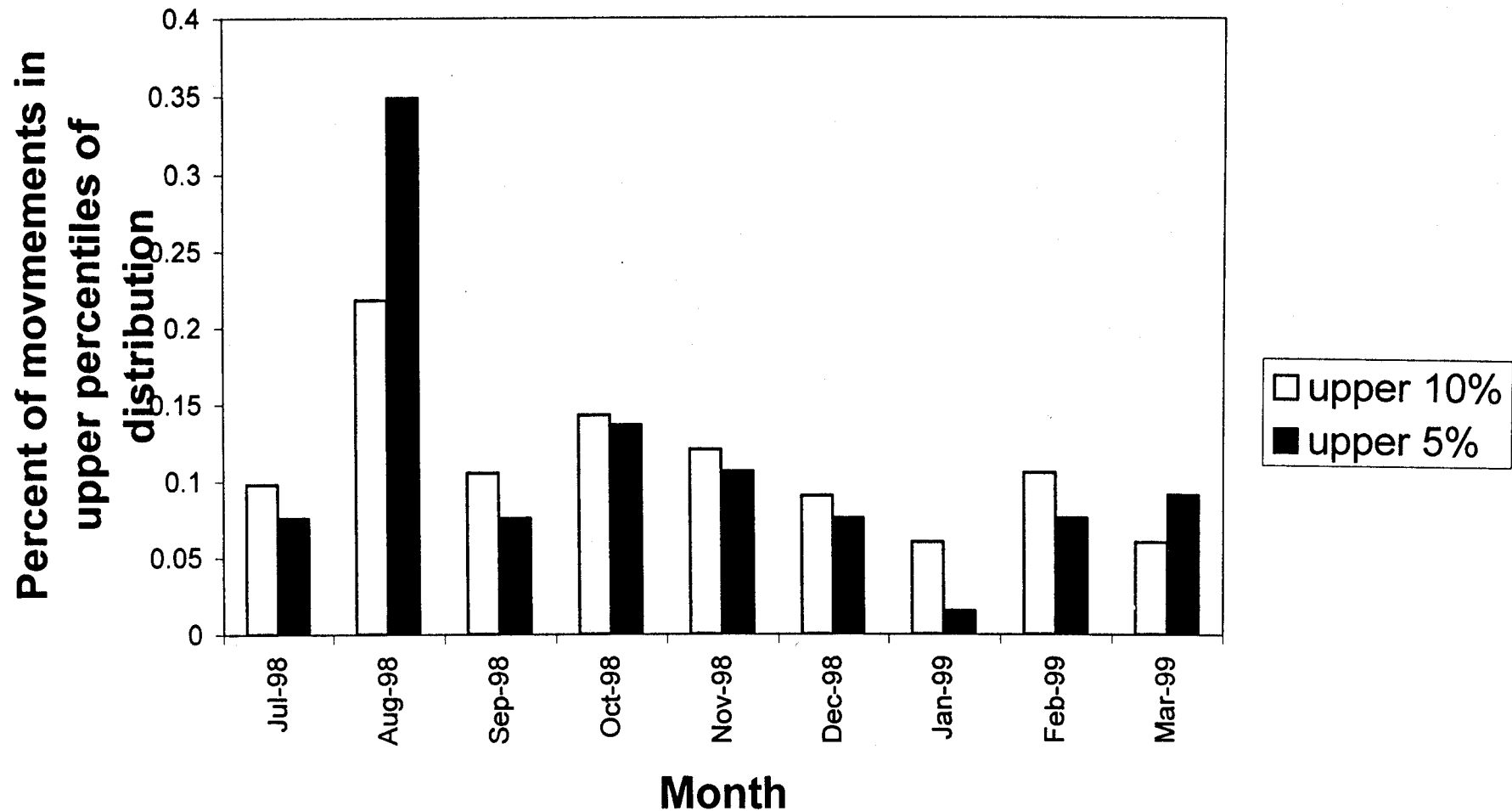


FIGURE 12. Distribution of distances between consecutive resightings of banded juvenile and adult Cape Sable seaside sparrows

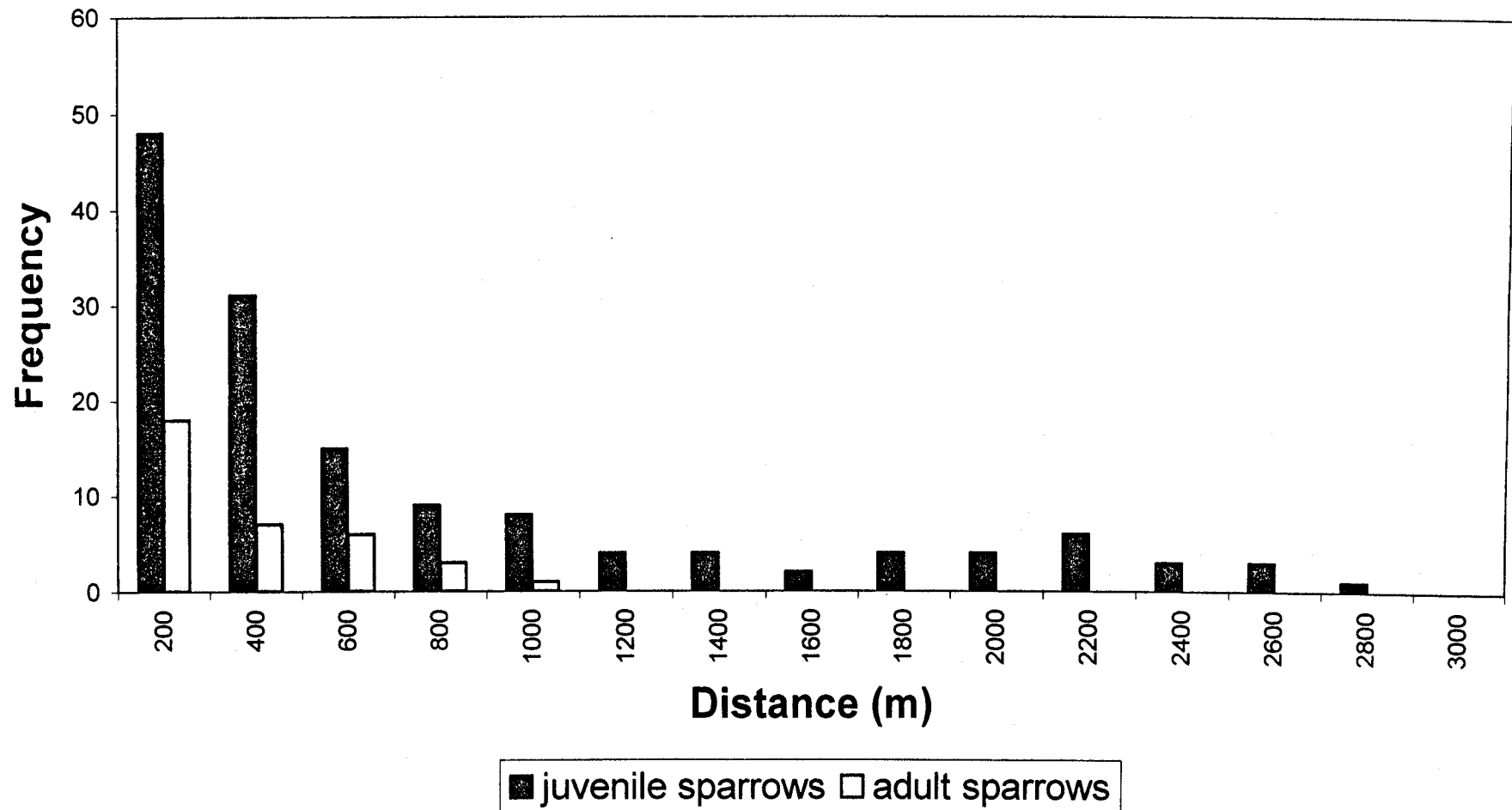


FIGURE 13. Home ranges and sparrow locations at the HR site, 1997-1998 field season

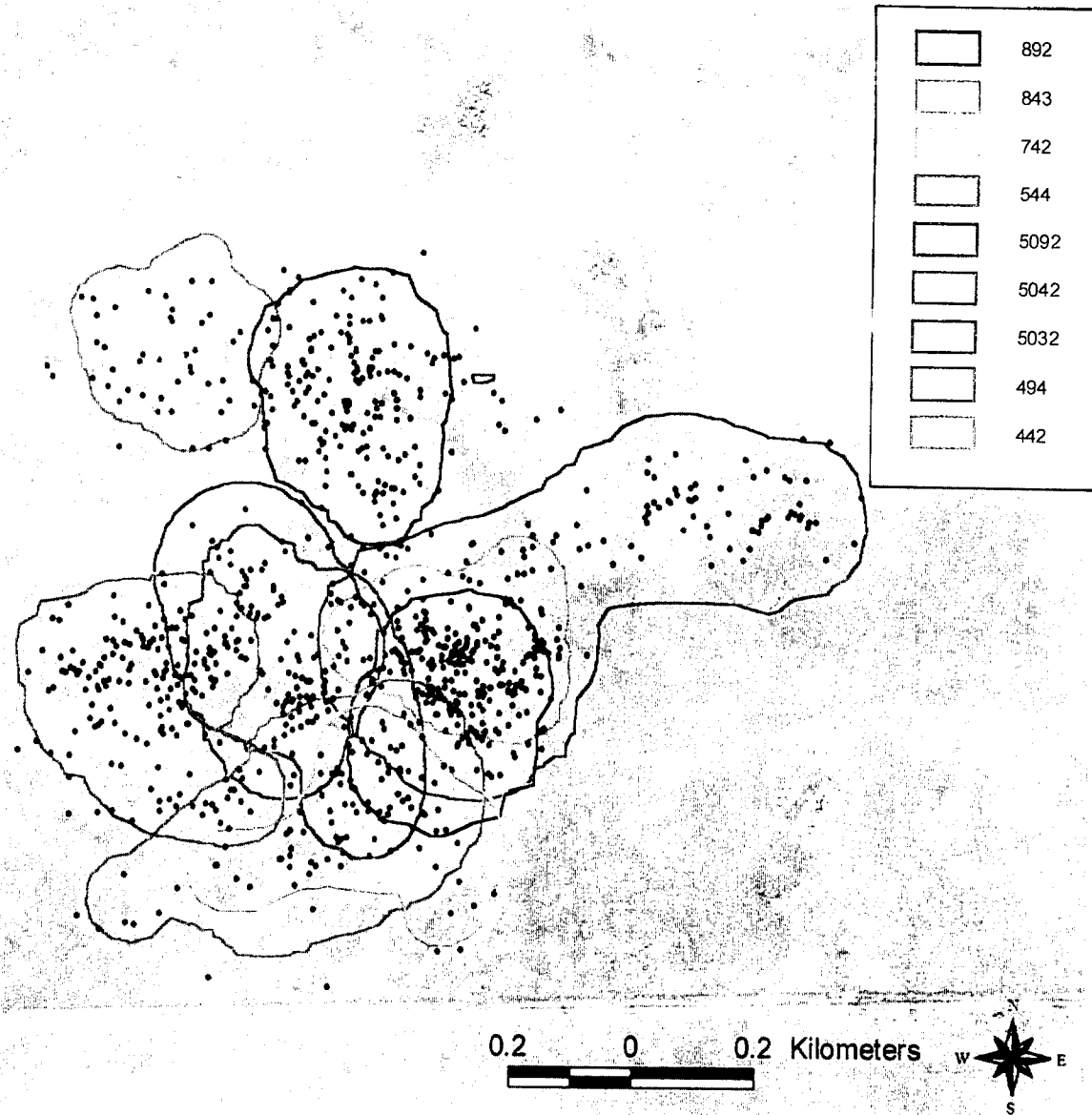


FIGURE 14. Home ranges and sparrow locations on the EI site, 1997-1998 field season

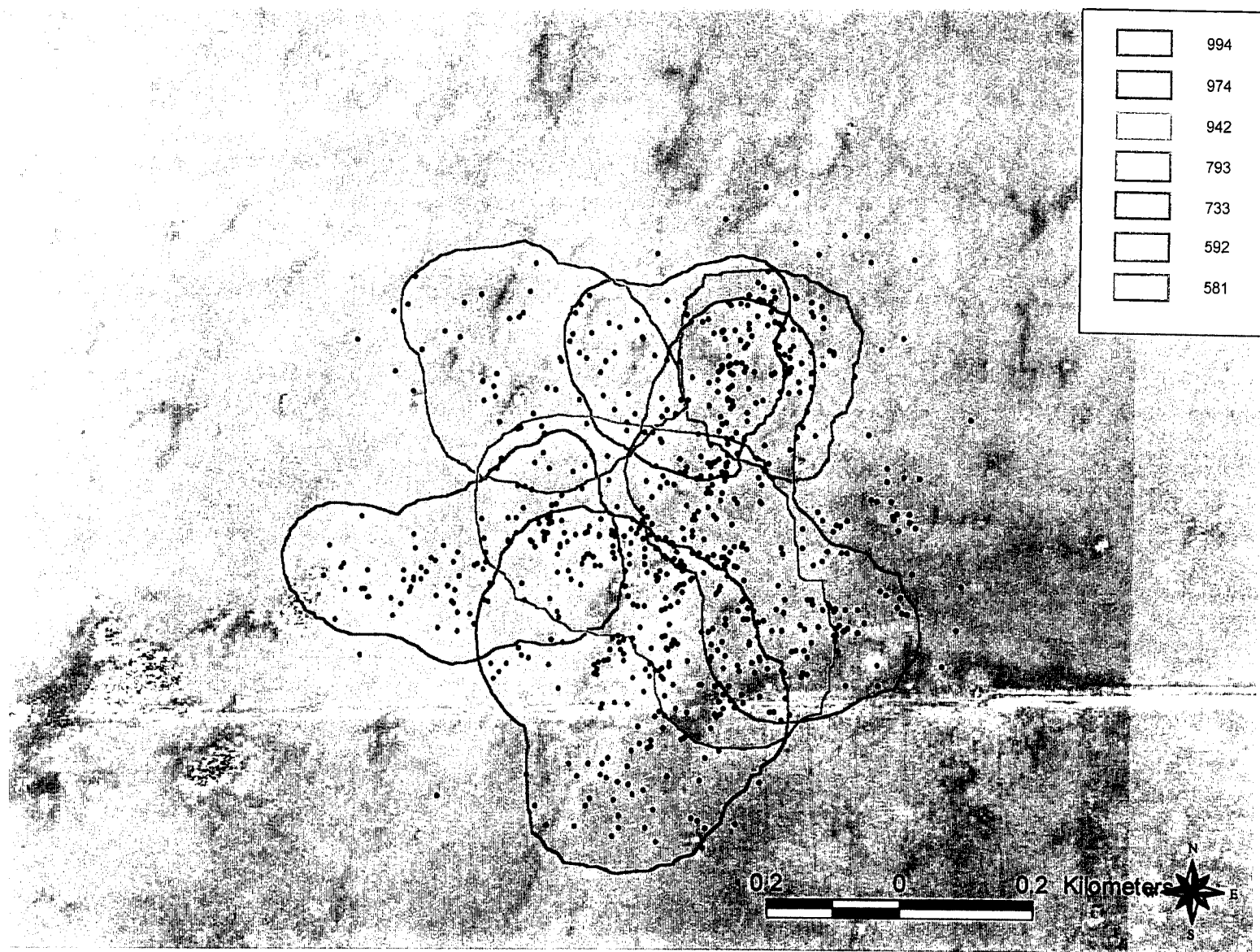


FIGURE 15. Home ranges and sparrow locations at the HR site, 1998-1999 field season



FIGURE 16. Home ranges and sparrow locations at the EI site, 1998-1999 field season

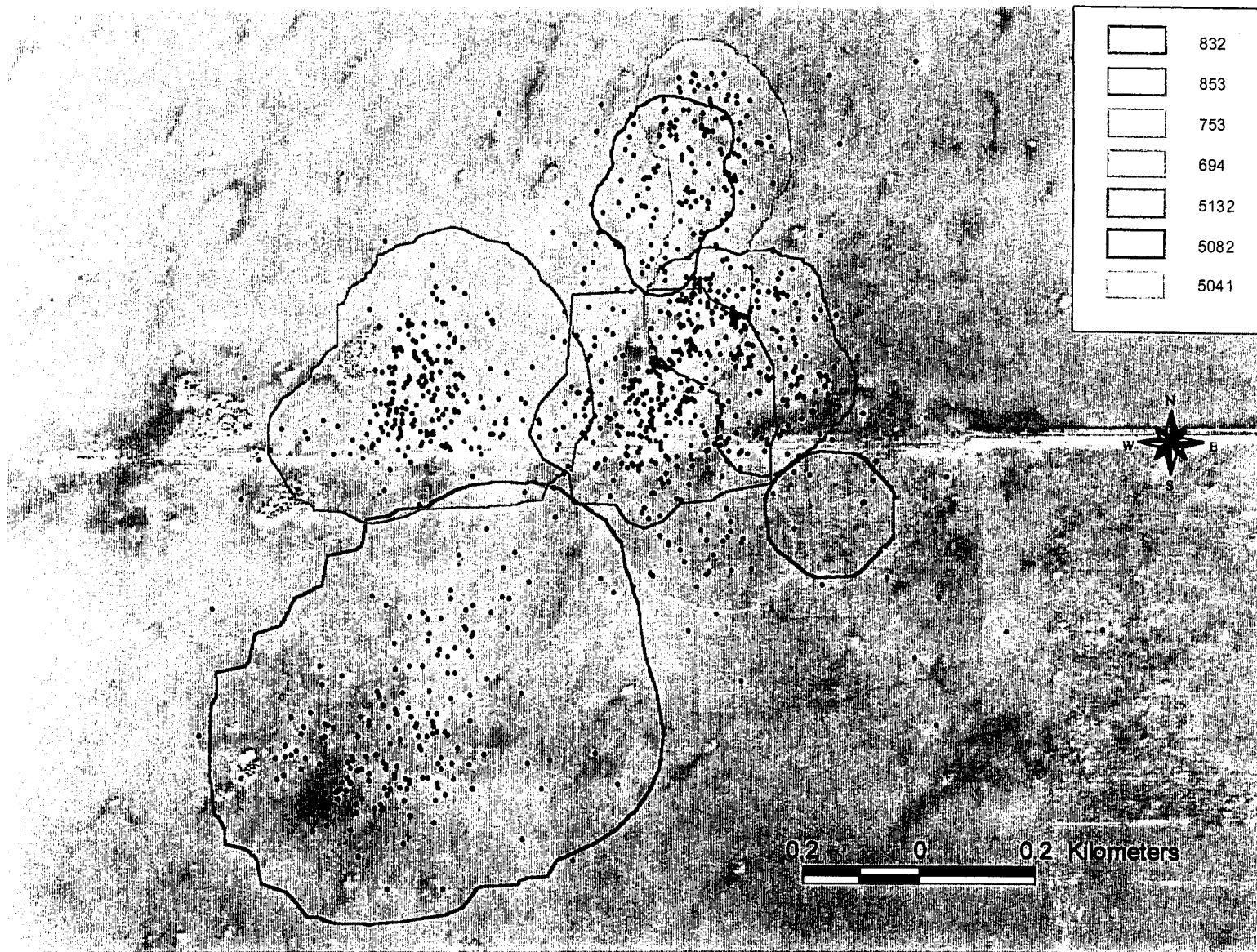


Figure 17. All Cape Sable seaside sparrow home ranges recorded during the 1998-1999 field season

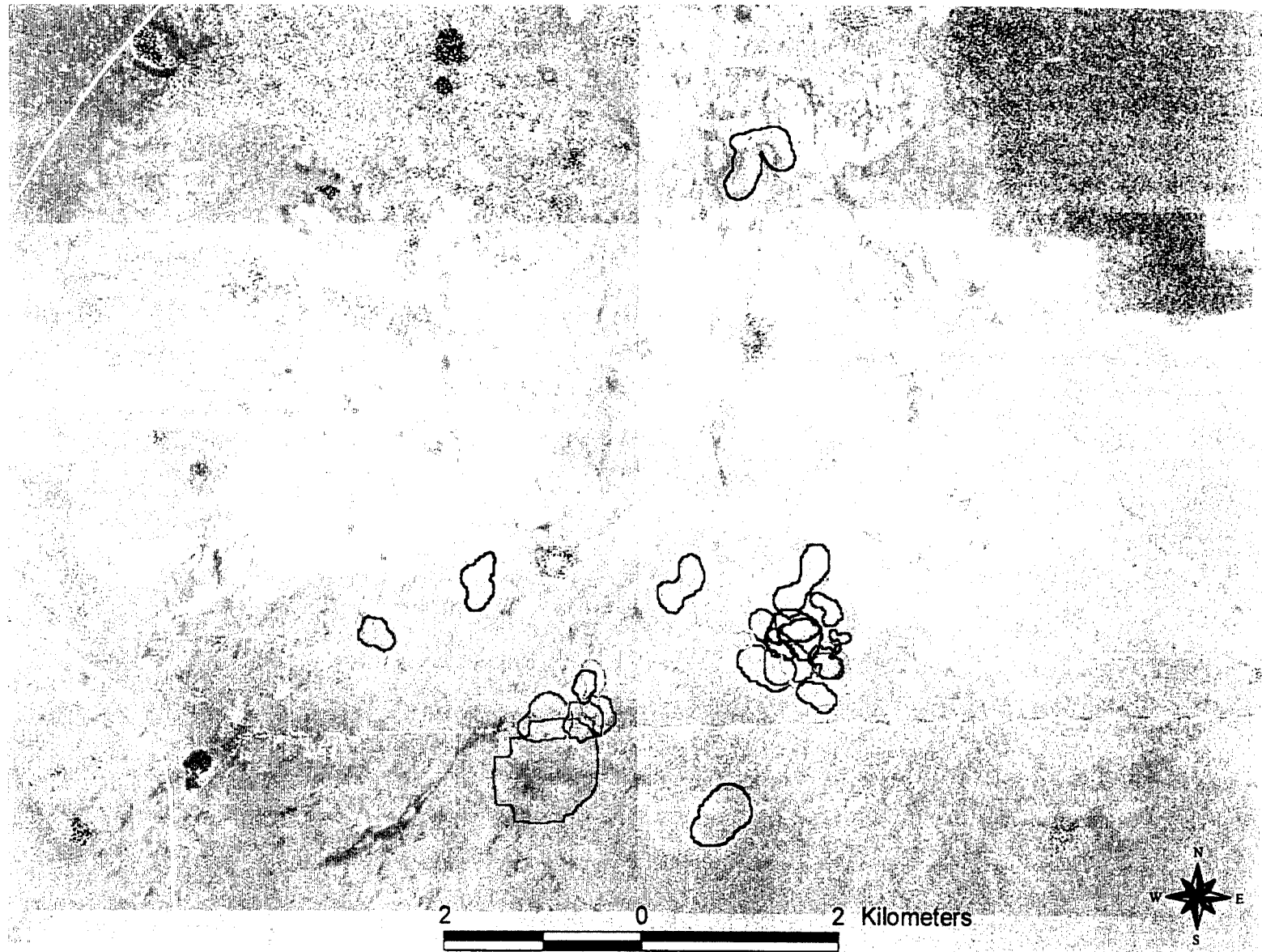


**FIGURE 18. Water depth over time at HR and EI sites,
and at P46 monitoring station**

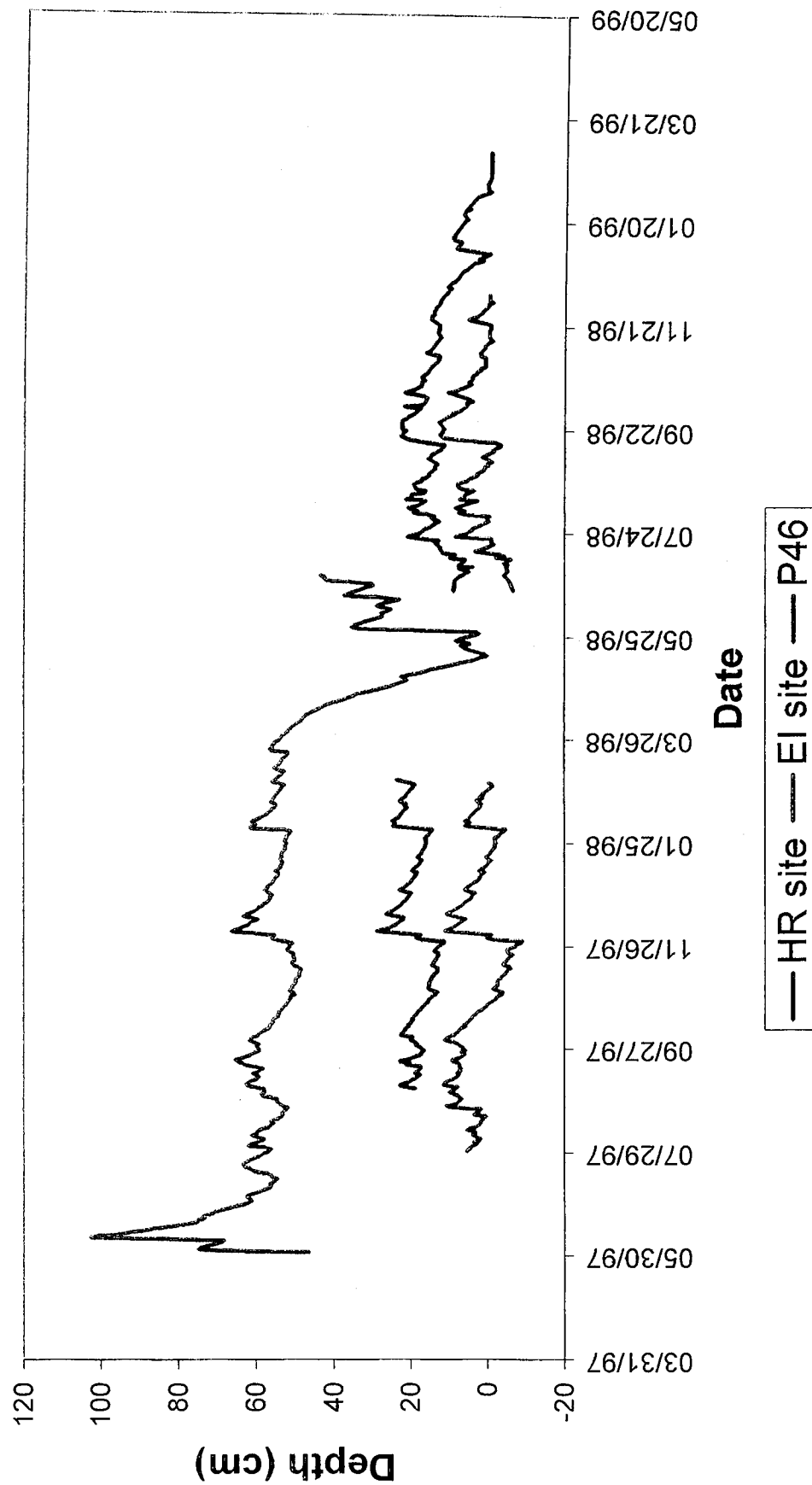


FIGURE 20. Pseudotopography at the EI site

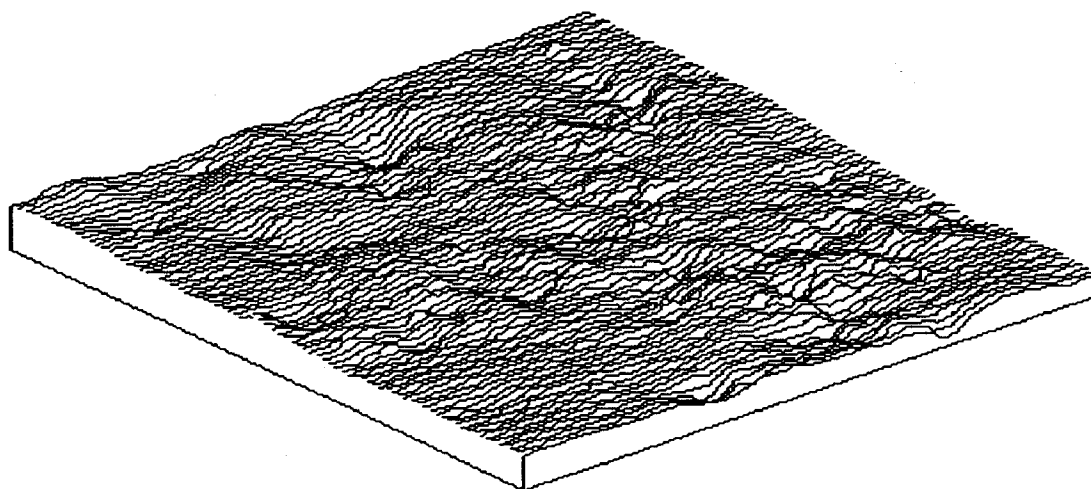


FIGURE 21. *Schizocyrium* cover use and availability by year and site

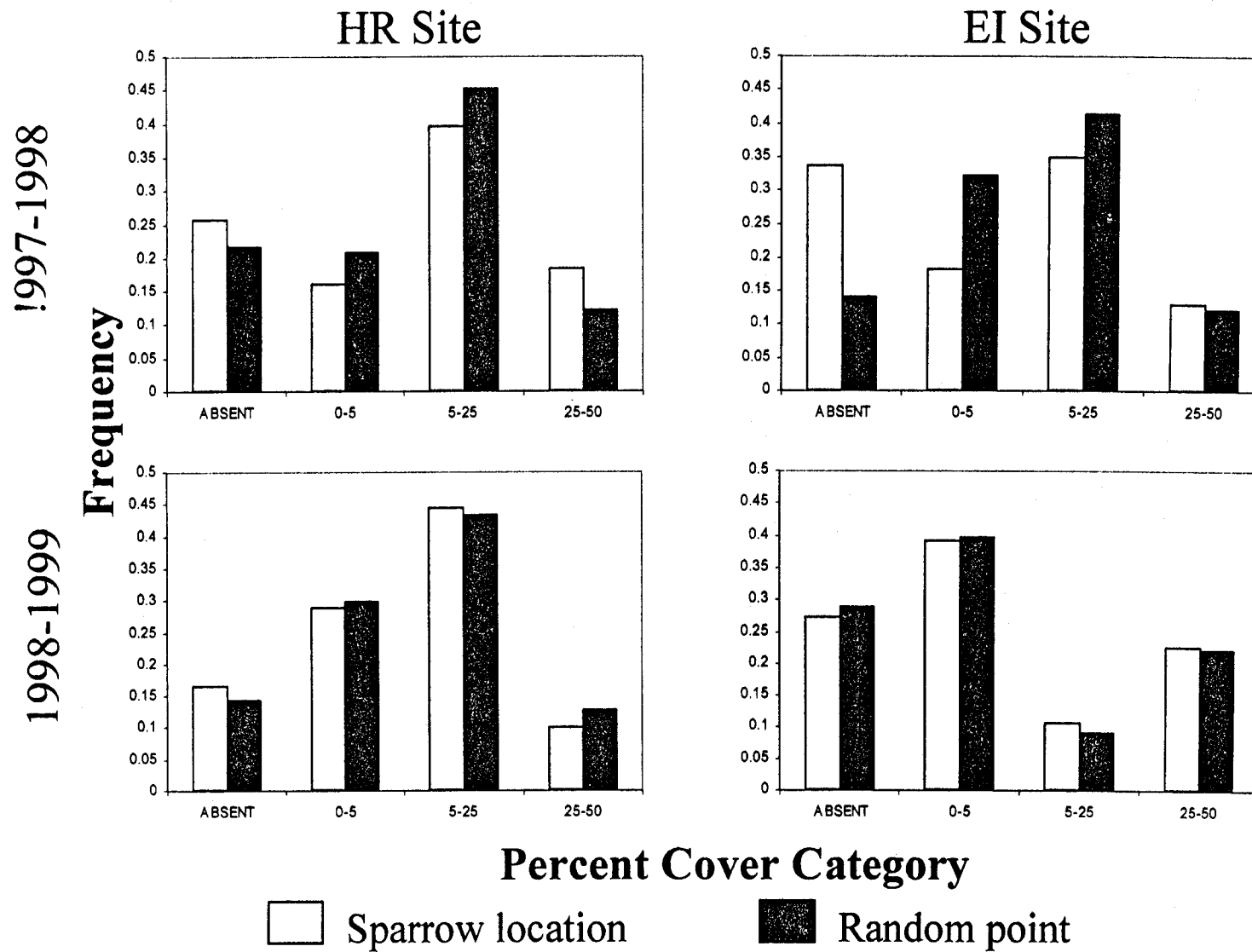


FIGURE 22. Sawgrass cover use and availability by year and site

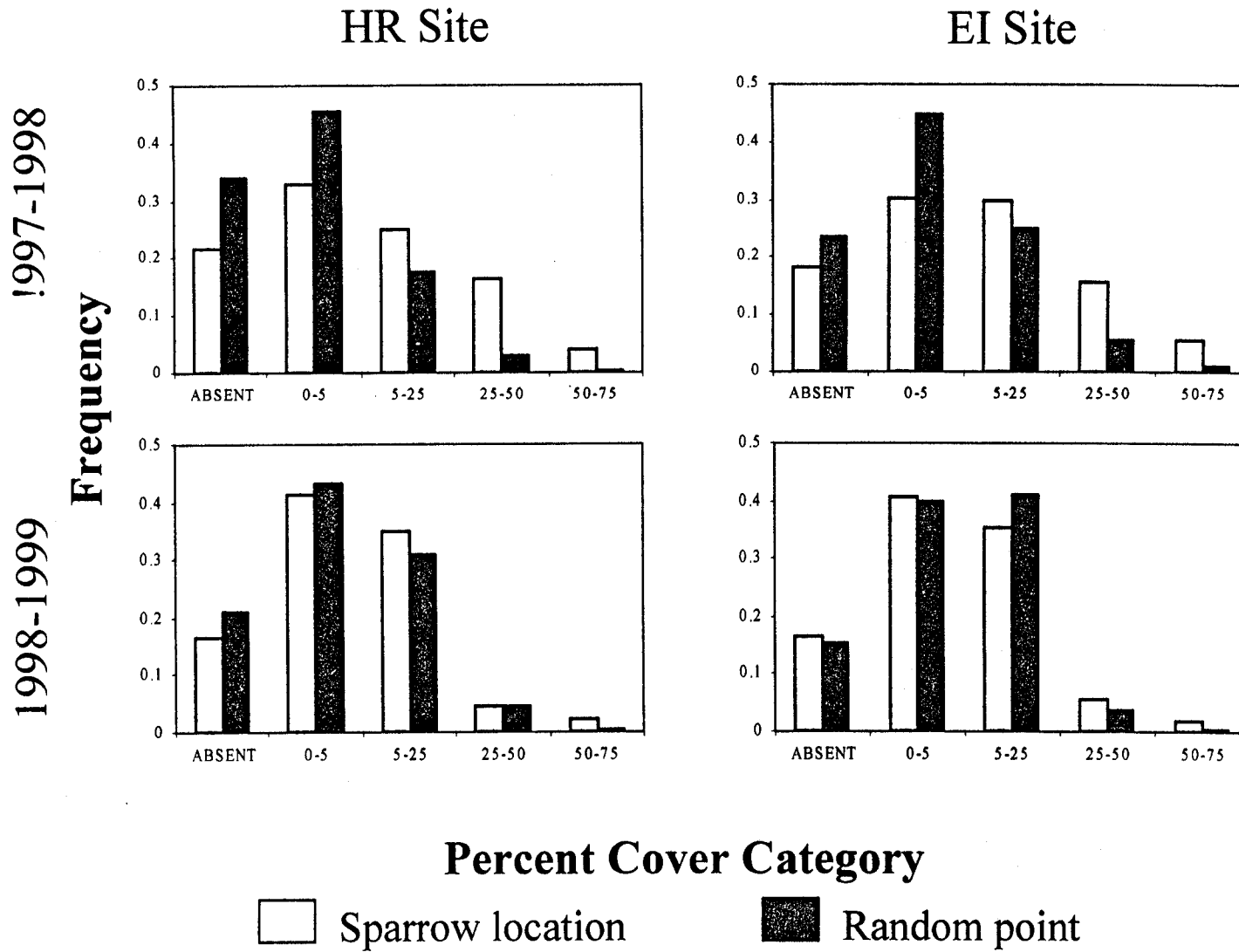


FIGURE 23. Litter cover use and availability by year and site

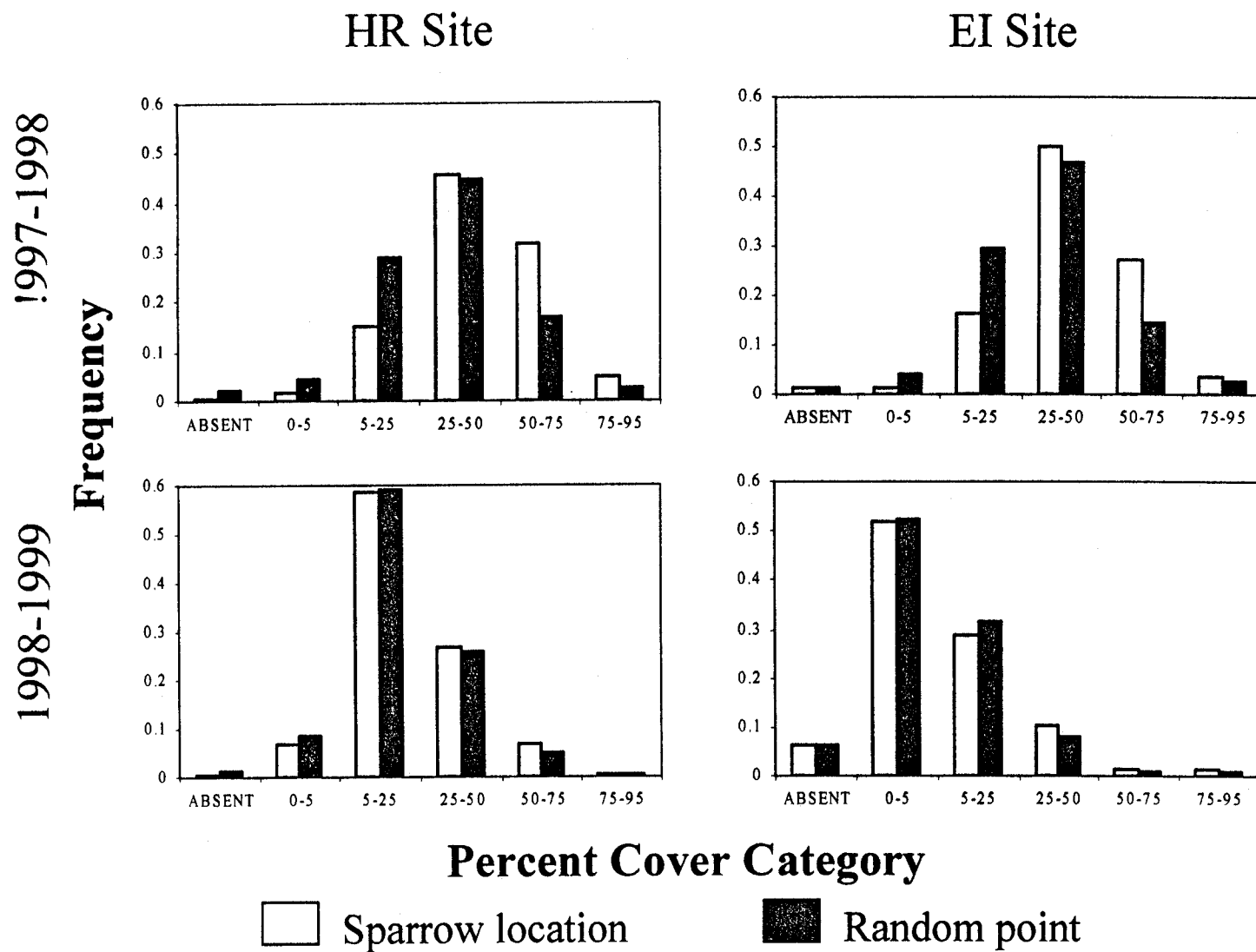


FIGURE 24. Open cover use and availability by year and site

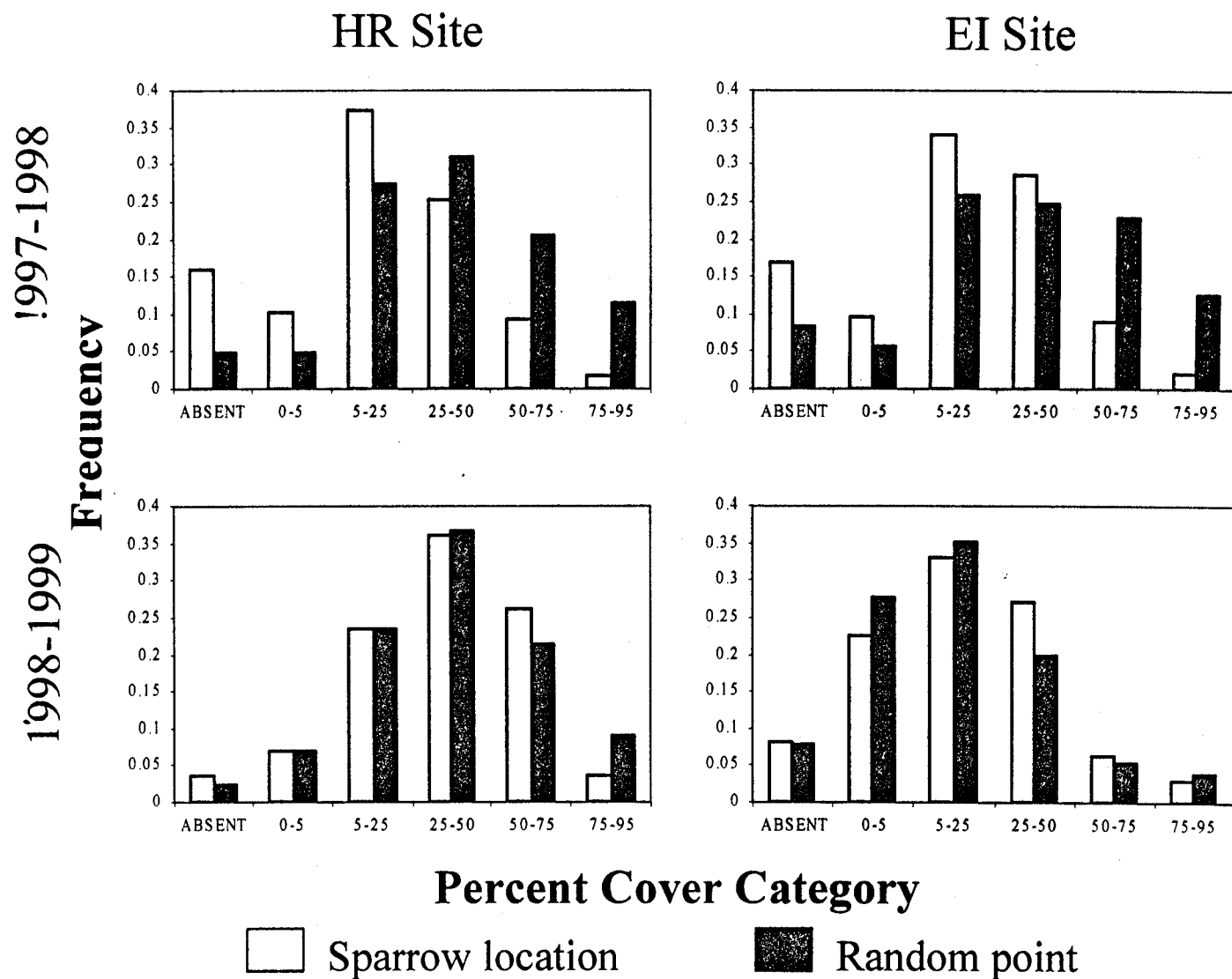


FIGURE 25. Rush cover use and availability by year and site

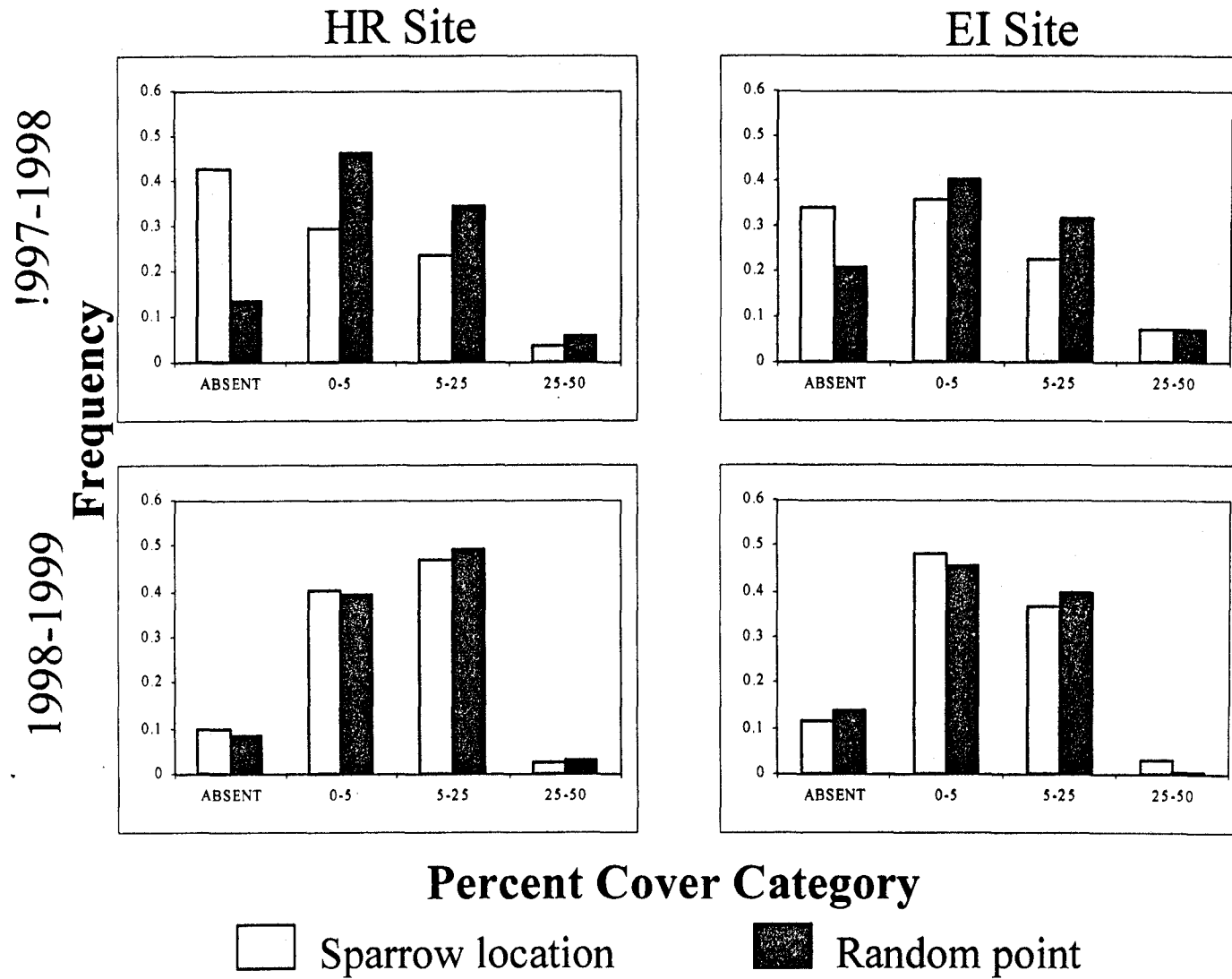


FIGURE 26. *Schizocyrium* cover at sparrow locations plotted relative to average water depth at study site

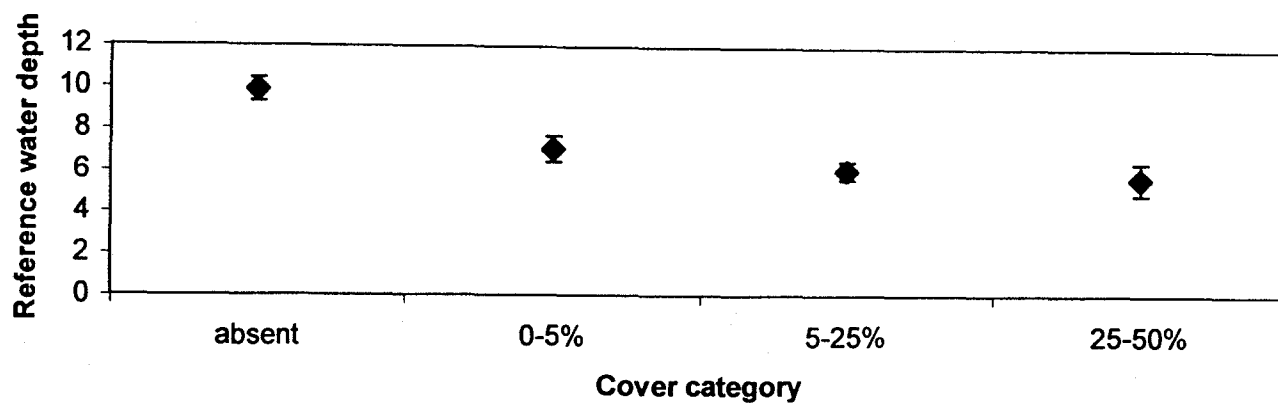


FIGURE 27. Sawgrass cover at sparrow locations plotted against reference water depth

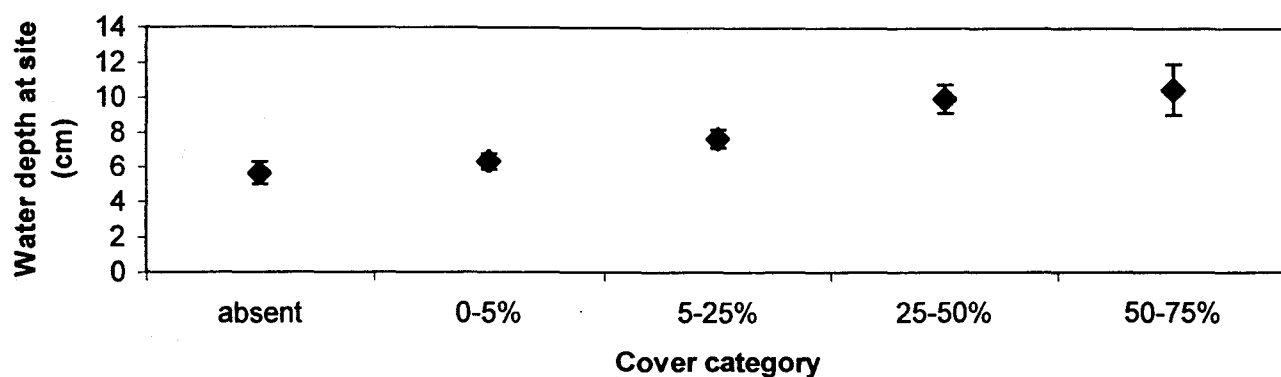


FIGURE 28. Rush cover at sparrow locations plotted relative to reference water depth at site

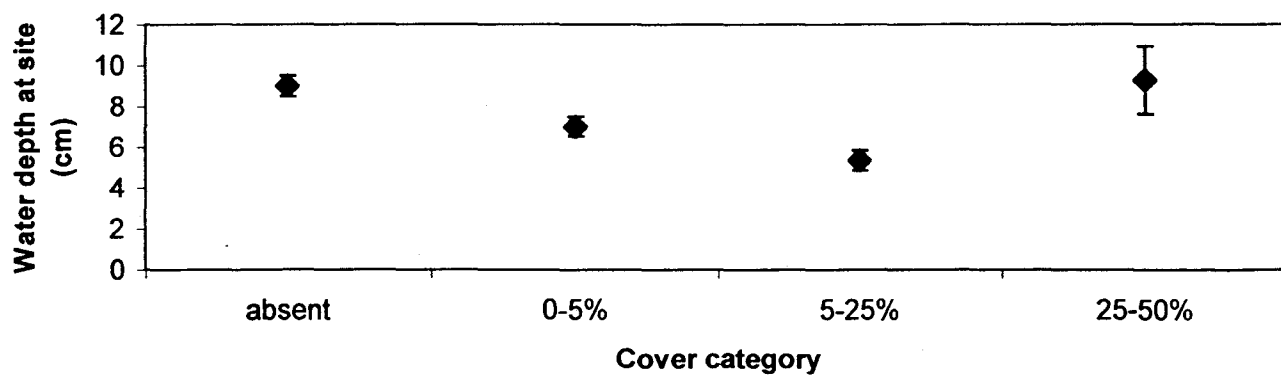


FIGURE 29. Litter cover at sparrow locations plotted relative to reference water depth at site

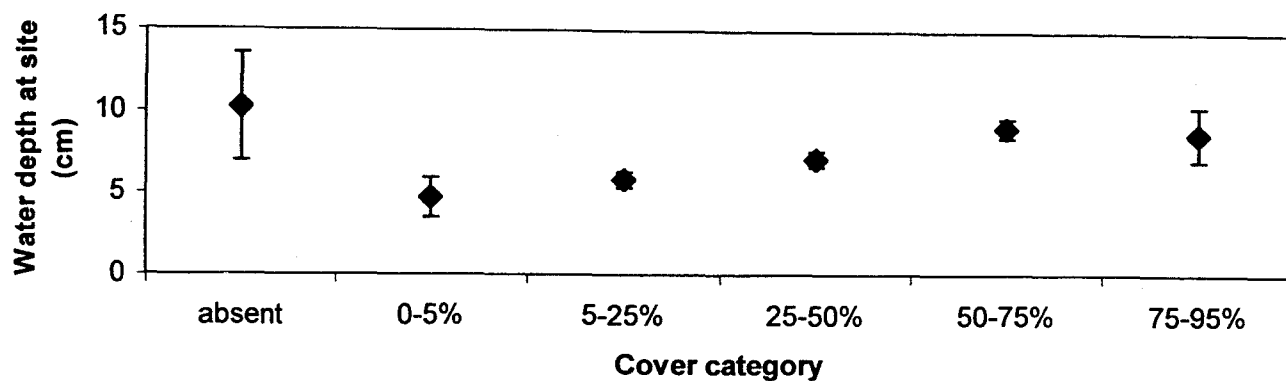


FIGURE 30. Open cover at sparrow locations plotted relative to water depth at site

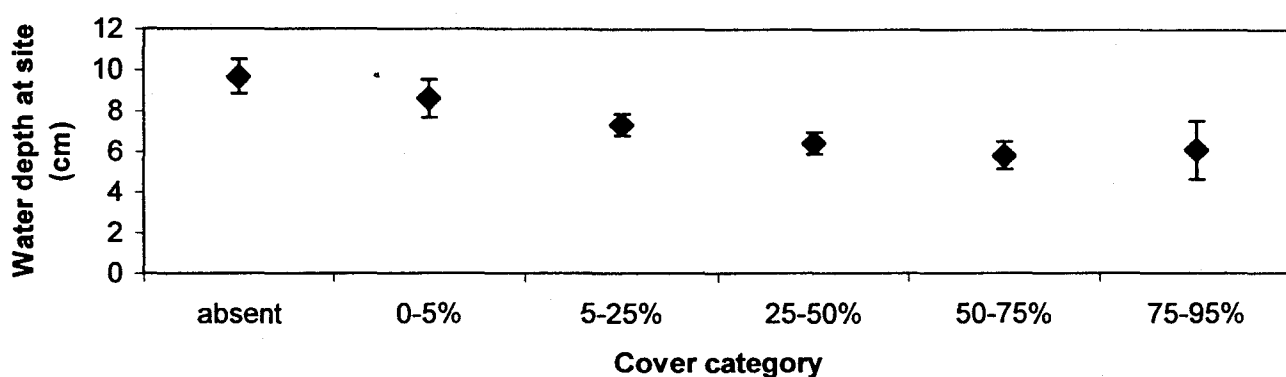


FIGURE 31. Black-topped sedge cover at sparrow locations plotted against water depth

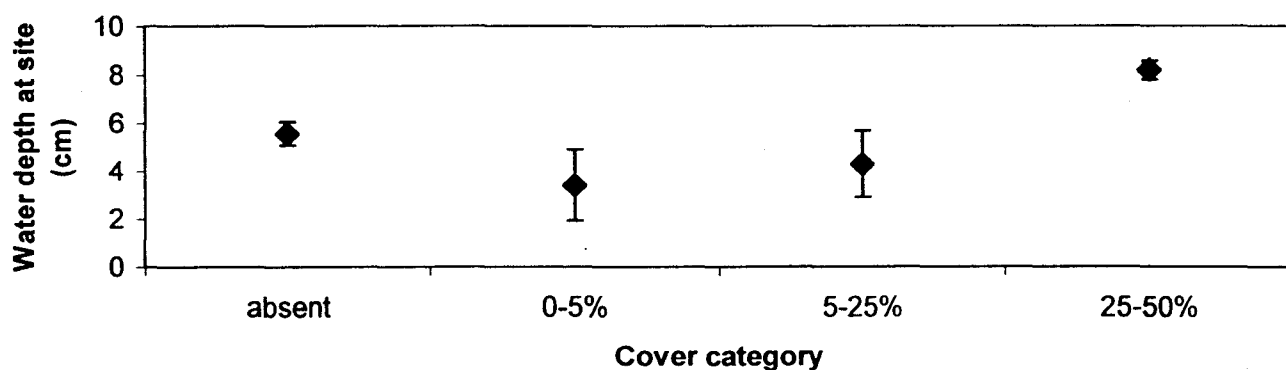


FIGURE 32. Resighting probabilities estimated using MARK, based on resighting data for 93 Cape Sable seaside sparrows, Apr 1998 - Feb 1999.

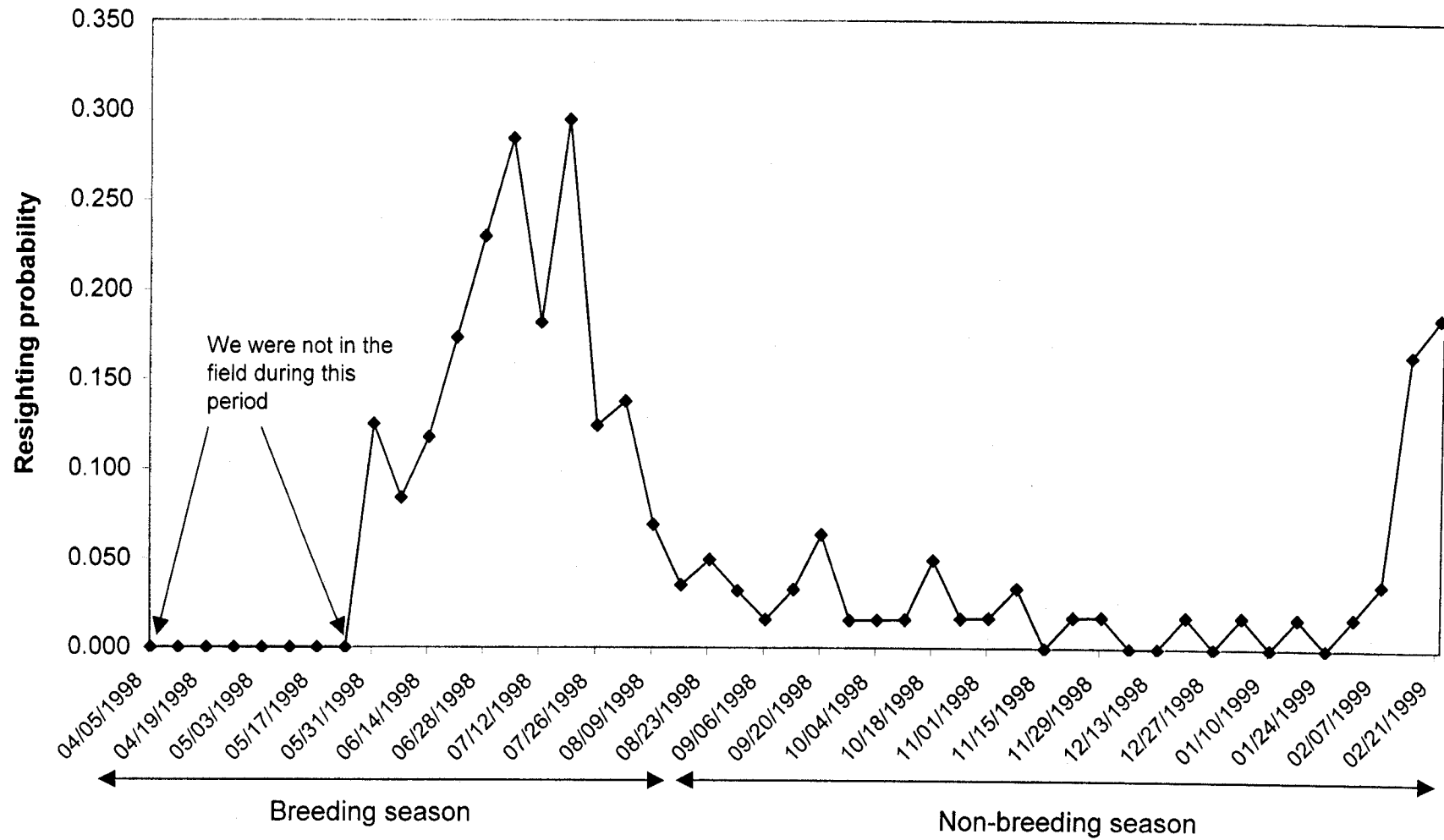


**FIGURE 33. Radiograph of cottonmouth showing ingested
Cape Sable seaside sparrow and transmitter**

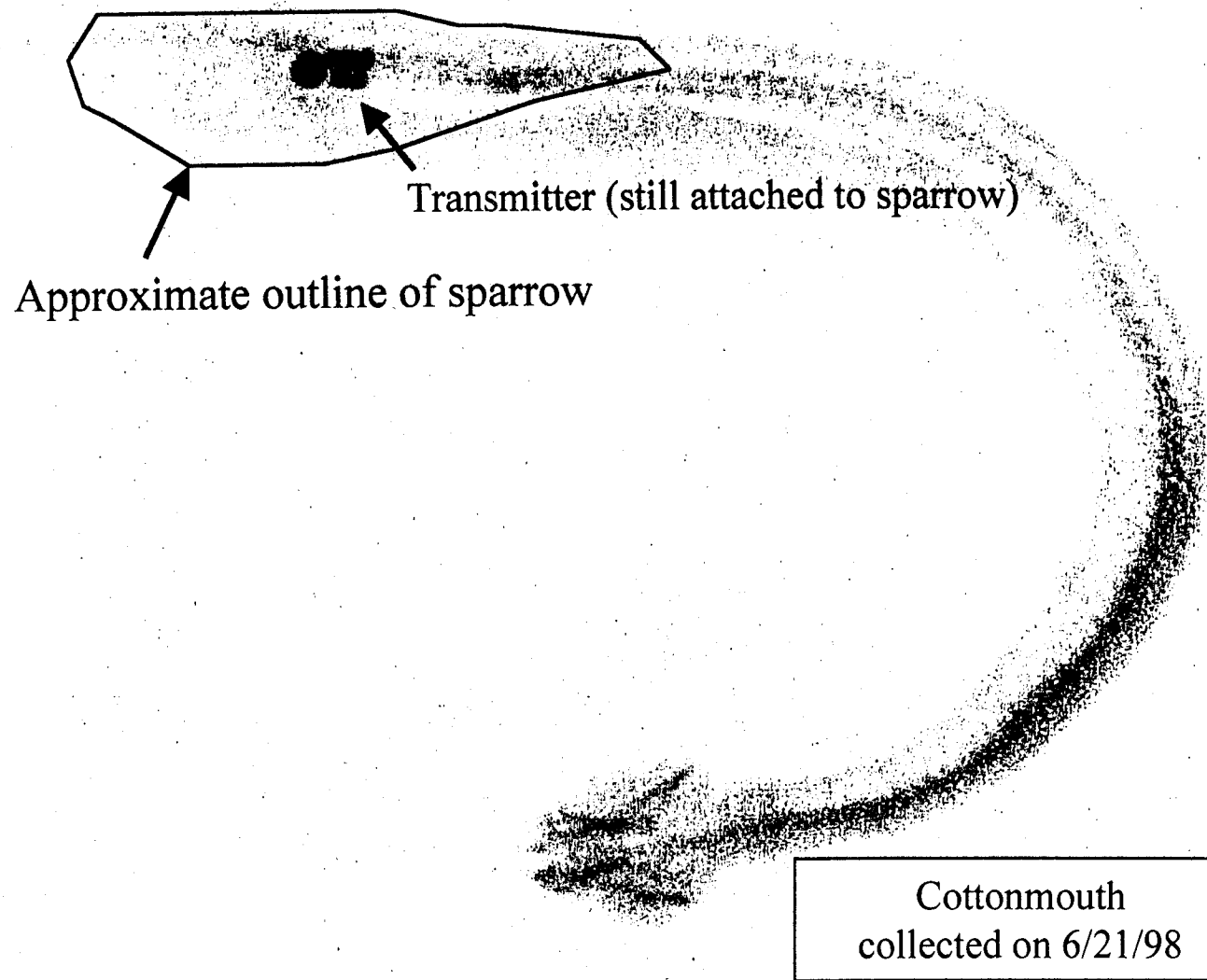
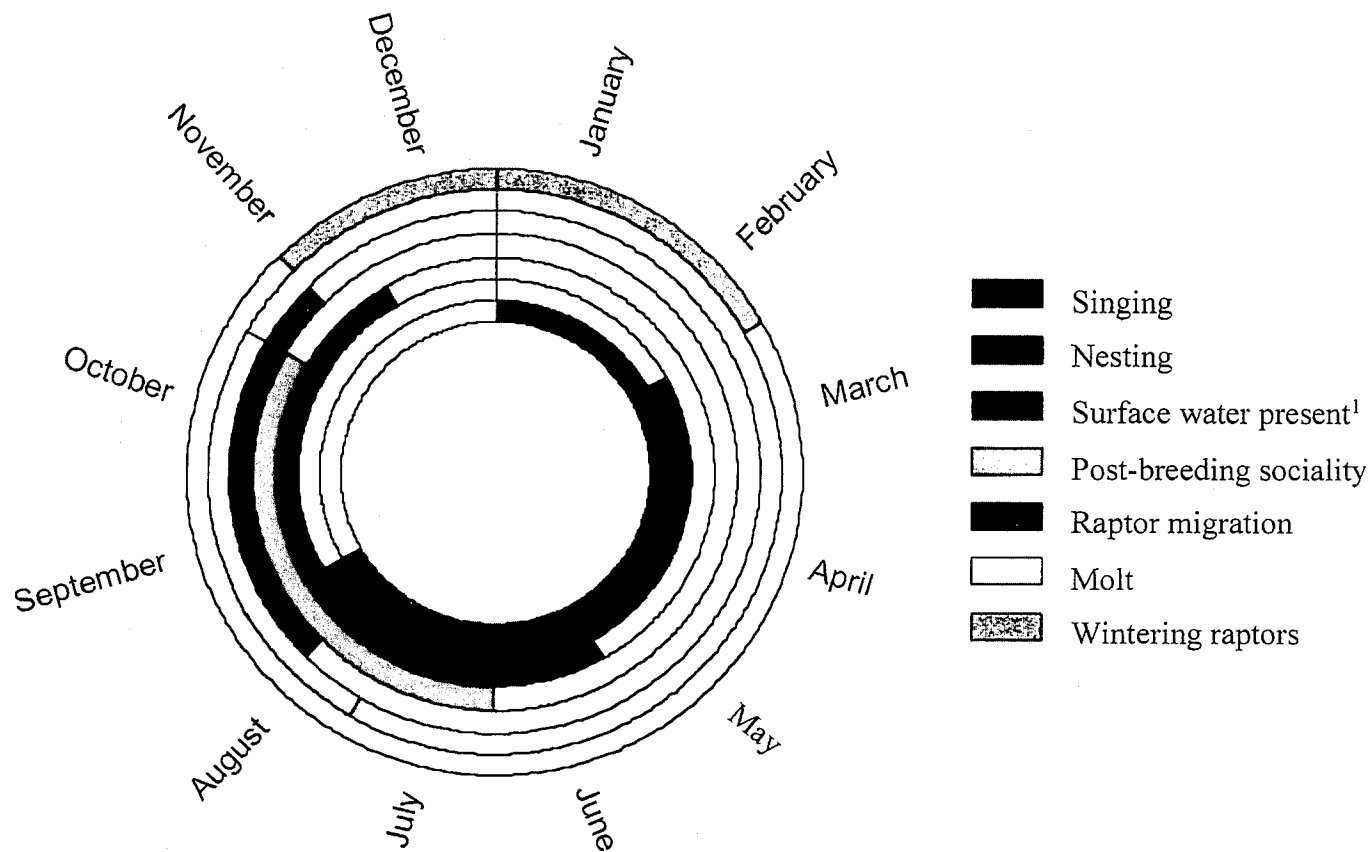


FIGURE 34. Annual chronology of Cape Sable seaside sparrow behaviors and environmental conditions. Beginning and ending dates of behaviors may vary among years, and we present here only the observations of dates from 1997-1999.



¹ Average period of inundation based on 1966-1996 hydrological data from P-46 station, Everglades NP

APPENDIX 1. Accuracy assessment of non-differentially correcting GPS and recording compass bearings.

We conducted compass checks regularly to ensure that compasses were functioning normally and to provide estimates of sighting error. For compass checks, observers recorded the bearings from one reference post to several other posts in close proximity. We then compared the measured bearings with bearings calculated from the recorded GPS positions of reference posts. The sighting error is the difference between the expected and measured bearings, and we calculated a 95% confidence interval for compass bearings. We applied correction factors to compass bearings in our database when compass checks indicated compass malfunctions.

When no reference posts were visible, we used non-differentially correcting GPS to record locations. GPS positions collected over approximately 2 minutes (1 position per second) were averaged to determine each location.

We also conducted GPS calibrations to determine the error in GPS locations recorded without the use of differential corrections. We determined error by recording locations of reference posts with the non-differentially correcting GPS and then comparing these locations with those obtained using differentially corrected locations. For error calculations, we assumed that longitudinal and latitudinal errors did not differ, and all errors were represented as the straight-line distance between the recorded and 'actual' locations.

The 95% confidence interval around compass bearings varied by compass and observer. The overall average error was 2.4 degrees. Two compasses consistently read inaccurately by 4-9 degrees, and we made corrections in our database whenever appropriate. We also corrected bearings for the difference between magnetic north and

grid north to allow UTM calculations. Calculating a position error from triangulation must be done on a point-by-point basis after determining sighting error. We did not calculate position errors for triangulated locations.

To determine the 95% confidence interval for handheld GPS units, we recorded GPS locations for 1-2 minutes at 50 known points. The confidence interval that resulted was 46m. The difference between averaging 1-2 minutes had little effect on confidence intervals, and an additional minute of averaging yielded 3 m smaller confidence interval.

APPENDIX 2. Cape Sable seaside sparrows banded during the nonbreeding season radio telemetry project, Everglades National Park. Site 'HR' = Half-Raccoon, 'EI' = End of Ingraham, 'FS' = Far South. Color band codes are read in the following order: 1) left leg upper position, 2) left leg lower position, 3) right leg upper position, 4) right leg lower position. Color codes are: A = azure, B = dark blue, G = dark green, K = black, L = lime, P = purple, R = red, S = aluminum USFWS band (silver), W = white, Y = yellow. Age codes are: AHY = after-hatch-year, HY = hatch year (juvenile), U = undetermined.

Date	Time	Site	Recapture	USFWS Band	Color bands	Sex	Age	Transmitter attached?
07/26/97	7:20	HR	FALSE	148195801	YYPS	F	AHY	TRUE
07/26/97	9:35	HR	FALSE	148195802	YRPS	F	AHY	TRUE
07/27/97	8:20	HR	FALSE	148195803	YKPS	M	AHY	FALSE
07/27/97	8:40	HR	FALSE	148195804	YWPS	U	HY	TRUE
07/27/97	9:46	HR	FALSE	148195805	YBPS	M	AHY	TRUE
08/01/97	9:40	HR	FALSE	148195806	YAPS	U	AHY	FALSE
08/09/97	7:17	HR	FALSE	148195807	RYPS	F	AHY	FALSE
08/09/97	7:54	HR	FALSE	148195808	RRPS	M	AHY	TRUE
08/09/97	8:35	HR	FALSE	148195809	RKPS	U	HY	FALSE
08/09/97	9:45	HR	FALSE	148195810	RWPS	M	AHY	TRUE
08/10/97	7:36	HR	FALSE	148195811	RGPS	U	AHY	TRUE
08/10/97	8:24	HR	FALSE	148195812	RAPS	U	AHY	TRUE
08/21/97	7:10	HR	FALSE	148195813	RAPS	U	AHY	TRUE
09/04/97	9:23	EI	FALSE	148195814	KYPS	U	AHY	TRUE
10/31/97	10:50	FS	FALSE	148195814	KYPS	U	U	TRUE
09/04/97	10:11	EI	FALSE	148195815	KRPS	U	AHY	TRUE
09/05/97	8:18	EI	FALSE	148195816	KKPS	U	U	TRUE
09/05/97	8:30	EI	FALSE	148195817	KWPS	U	U	TRUE
09/19/97	9:09	HR	FALSE	148195818	KBPS	U	HY	FALSE
09/20/97	8:20	EI	FALSE	148195819	KGPS	U	U	TRUE
10/05/97	8:42	HR	FALSE	148195820	WYPS	U	U	FALSE
10/31/97	9:38	FS	FALSE	148195821	KAPS	U	U	FALSE
10/31/97	10:28	FS	FALSE	148195822	WRPS	U	U	FALSE
11/01/97	9:28	EI	FALSE	148195823	WKPS	U	U	TRUE
11/01/97	10:08	EI	FALSE	148195824	VWPS	U	U	TRUE
11/11/97	10:06	HR	FALSE	148195825	WBPS	U	U	TRUE
11/11/97	10:47	HR	FALSE	148195826	WGPS	U	U	TRUE
11/12/97	9:15	EI	FALSE	148195827	WAPS	U	U	TRUE
11/12/97	9:15	EI	FALSE	148195828	BYPS	U	U	TRUE
11/20/97	11:23	HR	FALSE	148195829	BRPS	U	U	TRUE
11/20/97	12:18	HR	FALSE	148195830	BKPS	U	U	FALSE
06/16/98	8:20	EI	FALSE	148195831	BBPS	F	AHY	TRUE
01/16/98	11:12	FS	FALSE	148195832	BYPS	U	U	FALSE
06/16/98	9:35	EI	FALSE	148195833	BGPS	U	HY	TRUE
06/17/98	7:10	EI	FALSE	148195834	BAPS	U	HY	FALSE
06/17/98	7:10	EI	FALSE	148195835	GYPs	U	HY	FALSE
06/17/98	8:45	EI	FALSE	148195836	PSGR	U	HY	FALSE
06/21/98	7:30	HR	FALSE	148195837	GKPS	U	HY	TRUE
06/21/98	7:30	HR	FALSE	148195838	GWPS	U	HY	FALSE

Date	Time	Site	Recapture	USFWS Band	Color bands	Sex	Age	Transmitter attached?
06/21/98	8:35	HR	FALSE	148195839	GBPS	U	HY	TRUE
06/21/98	9:20	HR	FALSE	148195840	GGPS	F	AHY	TRUE
06/22/98	7:45	EI	FALSE	148195841	GAPS	U	HY	TRUE
06/22/98	7:45	EI	FALSE	148195842	AYPS	U	HY	FALSE
06/22/98	7:45	EI	FALSE	148195843	ARPS	U	HY	TRUE
06/22/98	7:45	EI	FALSE	148195844	AKPS	F	AHY	FALSE
06/22/98	8:45	EI	FALSE	148195845	AWPS	U	HY	FALSE
06/22/98	8:45	EI	FALSE	148195846	ABPS	U	HY	TRUE
06/22/98	8:45	EI	FALSE	148195847	AGPS	U	HY	TRUE
06/24/98	9:03	HR	FALSE	148195848	YLPS	U	HY	FALSE
06/24/98	9:03	HR	FALSE	148195849	LRPS	U	HY	FALSE
07/10/98	7:40	HR	FALSE	148195850	LYPS	U	HY	FALSE
07/10/98	7:40	HR	FALSE	148195851	LKPS	U	HY	TRUE
07/10/98	7:48	HR	FALSE	148195852	LWPS	M	AHY	TRUE
07/19/98	8:14	EI	FALSE	148195853	LBPS	F	AHY	TRUE
07/19/98	9:35	EI	FALSE	148195854	LGPS	U	HY	FALSE
07/19/98	9:35	EI	FALSE	148195855	LAPS	U	HY	FALSE
07/19/98	9:35	EI	FALSE	148195856	LLPS	U	HY	FALSE
07/19/98	9:35	EI	FALSE	148195857	RLPS	U	HY	FALSE
07/23/98	7:36	HR	FALSE	148195858	KLPS	F	AHY	TRUE
08/08/98	8:15	EI	FALSE	148195859	WLPS	U	HY	FALSE
08/08/98	8:15	EI	FALSE	148195860	BLPS	U	HY	FALSE
08/11/98	8:21	HR	FALSE	148195861	GLPS	U	HY	FALSE
08/11/98	9:18	HR	FALSE	148195862	ALPS	U	HY	FALSE
08/11/98	9:30	HR	FALSE	148195863	BLPS	F	AHY	TRUE
08/13/98	8:25	EI	FALSE	148195864	PSYY	M	AHY	TRUE
08/28/98	8:30	HR	FALSE	148195865	PSYR	U	HY	FALSE
08/28/98	8:30	HR	FALSE	148195866	PSYK	U	HY	FALSE
08/28/98	8:35	HR	FALSE	148195867	PSYW	U	HY	FALSE
08/28/98	8:30	HR	FALSE	148195868	PSYB	U	HY	TRUE
08/28/98	8:30	HR	FALSE	148195869	PSYG	U	HY	TRUE
08/28/98	8:30	HR	FALSE	148195870	PSYA	U	HY	FALSE
09/01/98	8:00	HR	FALSE	148195871	PSRY	U	HY	TRUE
09/01/98	9:20	HR	FALSE	148195872	PSRR	U	U	FALSE
09/05/98	8:16	EI	FALSE	148195873	PSRK	U	HY	FALSE
09/05/98	8:16	EI	FALSE	148195874	PSRW	U	HY	FALSE
09/07/98	9:14	EI	FALSE	148195875	PSRB	U	HY	FALSE
09/21/98	9:35	HR	FALSE	148195876	PSRG	U	HY	FALSE
09/21/98	10:00	HR	FALSE	148195877	PSRA	U	HY	FALSE
09/21/98	10:09	HR	FALSE	148195878	PSKY	U	HY	TRUE
09/22/98	9:12	EI	FALSE	148195879	PSKR	U	U	TRUE
10/03/98	9:24	HR	FALSE	148195880	PSKK	U	HY	FALSE
10/03/98	9:32	HR	FALSE	148195881	PSKW	U	HY	FALSE
11/08/98	9:30	EI	FALSE	148195882	PSKB	U	U	FALSE

Date	Time	Site	Recapture	USFWS Band	Color bands	Sex	Age	Transmitter attached?
11/13/98	10:00	EI	FALSE	148195883	PSKG	U	U	FALSE
12/05/98	10:40	HR	FALSE	148195884	-SKA	U	U	TRUE
12/07/98	9:40	HR	FALSE	148195885	-SWY	U	U	FALSE
12/15/98	10:05	HR	FALSE	148195886	PSWR	U	HY	FALSE
01/01/99	11:00	HR	FALSE	148195887	PSWK	U	U	FALSE
01/01/99	11:20	HR	FALSE	148195888	PSWW	U	U	FALSE
01/21/99	9:50	HR	FALSE	148195889	PSWB	U	U	FALSE
01/21/99	10:00	HR	FALSE	148195890	PSWG	U	U	FALSE
01/21/99	10:45	HR	FALSE	148195891	PSWA	U	U	FALSE
01/21/99	11:20	HR	FALSE	148195892	PSBY	U	U	FALSE
06/22/98	7:45	EI	TRUE	152175076	YSAB	U	HY	FALSE
09/07/98	9:50	EI	TRUE	152175097	GSKA	U	AHY	FALSE
09/22/98	9:00	EI	TRUE	152175098	GSWB	U	AHY	FALSE
06/22/98	7:45	EI	TRUE	152175619	YSBA	U	HY	FALSE
09/29/98	8:57	EI	TRUE	152175772	KGGS	U	AHY	FALSE
12/26/97	8:50	EI	TRUE	152175795	RWYS	U	U	FALSE
12/05/98	11:25	HR	TRUE	152175797	WRGS	F	AHY	FALSE
11/01/97	9:28	EI	TRUE	152175833	KBYS	U	U	FALSE
09/01/98	9:20	HR	TRUE	152175856	RR-S	M	AHY	FALSE
12/15/98	11:58	HR	TRUE	152175857	RKLS	M	AHY	FALSE
09/29/98	9:05	EI	TRUE	152175860	BK-S	U	U	FALSE
09/04/97	8:25	EI	TRUE	152175880	WKYS	U	AHY	FALSE

