NEST SUCCESS AND HABITAT SELECTION OF THE SEMIPALMATED PLOVER ON AKIMISKI ISLAND, NUNAVUT

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ABSTRACT.—We studied nest site selection by Semipalmated Plovers (*Charadrius semipalmatus*) to compare microhabitat characteristics at nest and random sites, and to compare successful and unsuccessful nests on the northern shore of Akimiski Island, Nunavut, during 2002. Nesting birds selected sites with more pebbles and less vegetative cover than randomly available in the environment. Nest sites also had smaller percentage of bare mud than random sites. Plovers selected sites within 100 m of Arctic Terns (*Sterna paradisaea*) more often than expected based on the distribution of random sites in the study area. Twenty-three of 41 (56%) nests hatched successfully. None of the microhabitat features that we measured predicted nest success. All 10 nests near the colony of Arctic Terns hatched, suggesting that interspecific associations are more reliable than habitat features for predicting nest success. *Received 10 May 2003, accepted 25 September 2003.*

Nest site selection in shorebirds has important consequences for their survival and reproduction (Dyrcz et al. 1981, Espie et al. 1996, Powell 2001). Although the behavioral mechanisms of selection are poorly understood, the outcome is a nonrandom distribution of nests among available sites (Cody 1985, Lauro and Nol 1995). Nest predation may be the most important selective pressure affecting nest success (Lauro and Nol 1995, Lloyd et al. 2000). If microhabitat differences exist between successful and unsuccessful sites, natural selection may modify adaptive strategies (e.g., which habitats are used for nesting) to reduce predation risk. While other factors such as access to food for adults and/or young (Lauro and Nol 1995) and interspecific interactions (Dyrcz et al. 1981, Burger 1987, Powell 2001), influence nest site selection, predation risk is more important in the immediate vicinity of the nest. This general principle is the basis for numerous studies attempting to associate microhabitat structures with used and available sites, as well as successful and unsuccessful sites (Flemming et al. 1992, Espie et al. 1996, Powell 2001).

The Semipalmated Plover (*Charadrius semipalmatus*) is a common shorebird of open habitats in the Arctic and sub-Arctic regions of North America (Nol and Blanken 1999).

There are numerous accounts of the breeding biology of this species (Sullivan Blanken and Nol 1998, Nol and Blanken 1999), but little quantitative information is available on microhabitat characteristics of their nest sites (Nol and Blanken 1999). This species and other members of the genus rely on crypsis to enhance nest success. Some authors have argued that objects near the nest increase crypsis (e.g., Graul 1973, Lloyd et al. 2000). Therefore, we might expect that features around the nest and variation in these features would be related to variation in reproductive success. Hence, we compared physical and vegetation characteristics of Semipalmated Plover nest sites to random sites, and of successful and unsuccessful nests on Akimiski Island, Nunavut, Canada.

METHODS

Study area.—We studied plovers nesting on the northern shore of Akimiski Island, Nunavut, Canada (53° 11′ N, 81° 35′ W) between 4 June and 29 July 2002. The 3,800-km² island is located approximately 20 km offshore from the mouth of the Attawapiskat River in western James Bay (Leafloor et al. 2000). Our approximately 14-km² study area consisted of intertidal and supratidal salt marshes, including strand beaches and sand-gravel depositional areas surrounded by mudflats. Semipalmated Plovers nested in various densities at these beaches and sand-gravel depositional areas. Vegetation changed along a gradient, and was dominated by creeking alkali grass (*Puccinellia phryganodes*) in the lower intertidal marsh to fescue (*Festuca rubra*), Arctic rush

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(*Juncus arcticus*), Baltic rush (*J. balticus*), and Hoppner's sedge (*Carex subspathacea*) in the upper intertidal marsh and supratidal marsh (Blaney and Kotanen 2001). The transition from supratidal marsh to freshwater areas was characterized by willow (*Salix* spp.) shrubs, interspersed with water sedge (*C. aquatilis*) and buttercup (*Ranunculus* spp.) around pools. Vegetation in the supratidal marsh has been moderately degraded by the foraging of nesting Canada Geese (*Branta canadensis*). A small (<20 pairs in a 17-ha area) Arctic Tern (*Sterna paradisaea*) colony was present within our study area.

Nest searching and monitoring.—We found nests by walking through potential breeding habitat using parental behavior (distraction displays, or crouching) as an indicator of presence of nesting pairs (Nol and Blanken 1999). We monitored nests every 1–4 days until we could determine nest fate. We defined each nest as successful if at least one egg hatched. We considered eggs abandoned if they were cold and/or no adults were in the area on two successive visits. We examined nests for evidence of predation (tracks, broken eggshells, or punctured eggs) or hatching (distraction displays, observation of adults with chicks, or clean eggshell remnants in the nest; Mabee 1997) if nest contents were gone prior to the estimated hatch date. We assumed 5 days for laying and 24 days for incubation (Nol and Blanken 1999).

Nesting habitat.—We documented physical and vegetation characteristics within a 1-m^2 quadrat centered on the nest using a Canon Powershot S40 digital camera (Canon Canada Inc., Mississauga, Ontario) at approximately 1.5 m above the nest (Flemming et al. 1992). We determined random sites within our study area by selecting numbers from a random numbers table and plotting the values in an X-Y coordinate system using ArcView (Environmental Systems Research Inst. 1999). We located these random sites using a Global Positioning System (GARMIN International Inc., Olathe, Kansas), and we eliminated from our sample those sites that were not located on potential nest substrates (e.g., a site on water).

For analyses of the image of each quadrat, we superimposed a grid of 400 5 × 5 cm cells using Paint Shop Pro (Jasc Software 2000).

We estimated percent cover of pebbles (<5 cm diameter), stones (5–10 cm), rocks (>10 cm), mollusc shells, sticks (>10 cm length), and bare mud (i.e., having neither vegetation nor pebbles) based on occurrence in these cells (Flemming et al. 1992). In situations where two or more substrate or vegetation characteristics occurred in each cell, we classified the cell by the dominant characteristic.

We estimated percent cover of low (<5 cm vegetation height) and tall vegetation (>5 cm) at the nest site, as well as vegetation height, using the mean of the values obtained at the four corners of the quadrat. We measured distances from the nest to the nearest 1-m^2 patch of vegetation, open water (coast of James Bay or small supratidal ponds), shrub or tree (area with >1 m vegetation height), and vertical obstruction (area with >10 cm diameter) using a 60-m tape, and/or pacing. We measured distances to the nearest shrub or tree, up to a maximum distance of 500 m. We estimated maximum length and width of the habitat patch (i.e., an area differing from its surroundings) that contained the nest site by measuring where the habitat changed (e.g., gravel to bare mud). We determined elevation by pulling a string placed at the nest cup to a permanent source of surface water, held the string horizontal, and measured the vertical distance between string and water. We determined slope by placing one end of a straight object of known length at the nest cup. The other end was touching the substrate. We raised this end until the object was parallel to the ground. We estimated slope with the TAN-1 function from the vertical distance of the object held level above the substrate, and length of the object. We estimated height of vertical obstruction at the four corners of the 1-m^2 quadrat with a tape measure. We estimated percent cover of vertical obstruction with the mean of the values obtained at the four corners of the quadrat using a transparent 20 × 20 cm checkerboard (100 2 × 2 cm cells) held vertically at the nest site.

Statistical analyses.—We eliminated from all analyses two habitat variables (percent cover of tall vegetation and sticks) that were absent from more than 25% of the nest and random sites. Sixteen variables were used to describe the structure of the microhabitat at nest and random sites (Table 1). We per-

TABLE 1. Eigenvectors, eigenvalues, and variances explained for principal components analysis of habitat variables measured at 42 Semipalmated Plover nest and 84 random sites on Akimiski Island, Nunavut, Canada, 2002. Correlation loadings $>|0.40|$ are in boldface.

Habitat variables	Eigenvectors		
	PC1	PC2	PC3
Vegetation height	−0.36	−0.30	−0.15
Distance to 1-m^2 vegetation	0.24	0.09	0.20
Distance to open water	0.15	0.03	−0.20
Distance to shrub or tree	0.27	0.15	−0.19
Distance to vertical obstruction	−0.05	0.30	−0.05
Length of habitat patch	0.28	0.07	−0.18
Width of habitat patch	0.39	−0.01	−0.26
Elevation	0.26	−0.29	−0.30
Slope	−0.11	−0.13	−0.14
Percent cover of vertical obstruction	−0.16	**−0.41**	−0.13
Percent cover of pebbles	**0.40**	−0.33	0.15
Percent cover of stones	0.00	−0.23	**0.42**
Percent cover of rocks	0.12	−0.29	**0.42**
Percent cover of mollusc shells	0.18	−0.05	−0.38
Percent cover of low vegetation	**−0.43**	−0.06	−0.31
Percent cover of bare mud	−0.07	**0.52**	0.13
Eigenvalue	2.94	2.62	1.76
Percent total variance	18.40	16.40	11.00

formed principal components analysis (PCA) using MINITAB 13.1 (MINITAB Statistical Software 2000) to summarize the patterns of covariation present in those variables. We retained six components based on eigenvalues >1.0, but we report only the three components which each explained $>10\%$ of the variance. We standardized all measurements. We compared the means of the six principal components for nest and random sites using independent *t*-tests, but report only statistically significant components. We considered a test to be statistically significant at the 5% level if $P \leq 0.008$ after we applied Bonferroni's correction to these data.

We performed logistic regression using SPSS 9.0 (SPSS, Inc. 1998) to model which microhabitat variables should be included in the final model with nest success as the binary response variable (Manly 1994). We constructed 91 potential models via a manual forward selection method, where we made univariate and multivariate comparisons of habitat variables between successful and unsuccessful nests.

We further excluded five variables (vegetation height, percent cover of stones, percent cover of mollusc shell, percent cover of low vegetation, and percent cover of bare mud) because they were absent at $>25\%$ of the nest sites. This approach resulted in eleven variables, which we transformed before analyses to improve the normality of their distributions. We arbitrarily divided distance to shrub or tree into one of six categories: <99 m, 100–199 m, 200–299 m, 300–399 m, 400–499 m, and >500 m. We determined correlation coefficients for pairs of habitat descriptors, and we retained those variables with $r < 0.6$. We eliminated the least significant correlated variables based upon partial correlations for distance to open water, length of substrate, and width of substrate. We retained the variable with the lowest standard error of the estimate for distance to 1-m^2 patch of vegetation and percent cover of pebbles. We used the variables: distance to open water, distance to vertical obstruction, distance to shrub or tree, elevation, slope, percent cover of vertical obstruction, percent cover of pebbles, and percent cover of rocks in our model. Unless otherwise stated, we set statistical significance at $\alpha = 0.05$.

RESULTS

Comparison of nest and random sites.—The PCA of 16 habitat variables measured at 42

TABLE 2. Means of the principal components, including the variables that loaded onto each component, were significantly different between Semipalmated Plover nest and random sites on Akimiski Island, Nunavut, Canada, 2002. Nest sites had more pebbles in the substrate and less vegetative cover (PC1), and greater vertical obstruction and less bare mud (PC2) than random sites.

| | Nest | | Random | | | | |
Component	Mean	SE	Mean	SE	t	df	P
PC1	0.7	0.3	−0.4	0.2	3.52	124	0.001
Percent cover of pebbles	63.6	4.3	30.4	3.9			
Percent cover of low vegetation	17.1	3.6	29.5	3.7			
PC2	−1.1	0.1	0.6	0.2	7.77	123	<0.001
Percent cover of obstruction	21.0	1.5	16.5	1.7			
Percent cover of bare mud	5.2	1.8	35.6	3.9			

nest and 84 random sites extracted six components that accounted for 67% of the total variance in the sample. PC1 represented a gradient from sites with large proportions of vegetative cover (negative values) to large proportions of pebble substrate (positive values; Table 1). Nest sites had significantly greater values of PC1 than random sites, indicating more pebbles in the substrate and less vegetative cover (Table 2). PC2 represented a gradient of visibility with negative values indicating more vertical obstruction while positive values indicated a greater percentage of bare mud. Nest sites had less mud than random sites (Table 2). PC2, PC3, and PC4 did not differ significantly between nest and random sites (powers < 0.30). The proportion of nest sites that were <100 m from the Arctic Tern colony (10 of 42, 24%) was significantly greater than proportion of random sites <100 m to the colony (5 of 84, 6%; Fisher's exact test, $P = 0.005$).

Probability of nest success.—Nest fate was known for all nests (18 unsuccessful and 23 successful) but one. Although multiple logistic regression showed no significant relationship between nest success and habitat variables ($\chi^2 = 8.38$, df = 8, $P = 0.40$), distance to vertical obstruction contributed significantly to the model when this habitat feature was entered individually (Wald's $\chi^2 = 4.04$, df = 1, $P = 0.044$; Table 3). In the univariate analysis, distance to vertical obstructions was not significantly different between successful and unsuccessful nests (means of 0.45 m ± 0.20 SE and 0.19 m ± 0.08 SE; respectively; $\chi^2 = 2.93$, df = 1, $P = 0.083$), although power for this test was low (0.40). The final multivariate model retained distance to the nearest vertical obstruction and slope ($\chi^2 = 5.45$, df = 2, $P = 0.065$). The proportion of successful nests <100 m from the Arctic Tern colony (10 of 10, 100%) was significantly greater than the proportion of successful nests found farther from the colony (13 of 31, 42%; Fisher's exact test, $P = 0.026$). Habitat characteristics be-

TABLE 3. Multiple logistic regression of the relationship between Semipalmated Plover nest success and individual habitat variables on Akimiski Island, Nunavut, Canada, 2002.

| | Successful | | Unsuccessful | | | |
Habitat variable	Mean	SE	Mean	SE	Wald's χ^2	P
Distance to open water (m)	6.0	1.4	5.4	1.5	0.03	0.85
Distance to shrub or tree (m)	4.3	0.4	4.1	0.5	0.01	0.91
Distance to vertical obstruction[1] (m)	0.5	0.2	0.2	0.1	4.04	0.04
Elevation (cm)	22.1	1.2	21.9	1.3	0.41	0.50
Slope (°)	1.6	0.1	2.5	0.2	3.00	0.08
Percent cover of vertical obstruction	19.1	1.1	18.7	1.1	0.63	0.43
Percent cover of pebbles	60.0	6.7	67.1	5.2	0.42	0.52
Percent cover of rocks	1.9	0.2	2.5	0.3	0.46	0.50

[1] Logistic regression ($\chi^2 = 2.93$, $P = 0.083$, power = 0.40) showed no difference between successful and unsuccessful nests.

tween successful nests near to and far from the tern colony were not significantly different ($P > 0.14$).

DISCUSSION

Semipalmated Plovers placed their nests nonrandomly with respect to substrate and vegetation characteristics, but these microhabitat characteristics were not associated with nest success. Most nest sites contained >10% pebble substrate, and this was significantly greater than the proportion available in the surrounding environment. Similarly, other members of this genus (Piping Plovers, *C. melodus*: Burger 1987, Flemming et al. 1992; Killdeer, *C. vociferus*: Nol and Lambert 1984; Snowy Plovers, *C. alexandrinus*: Powell 2001; Mountain Plovers, *C. montanus*: Olson and Edge 1985) selected nest sites in microhabitats with a larger pebble component than that randomly available in the environment. Pebbles may help camouflage the eggs and chicks against the surrounding environment to reduce the risk of predation (Flemming et al. 1992). Gotmark et al. (1995) reported two types of nest concealment: concealment by vegetation and concealment by cryptic coloration of incubating birds and their eggs. Although vegetative cover may provide disruptive camouflage or concealment of incubating birds (Lloyd et al. 2000), we suggest that concealment by cryptic plumage may be more important than concealment by vegetation in plovers. Plovers selected nest sites with lower vegetative cover than that randomly available in the surrounding environment, suggesting a threshold where visibility is more advantageous than concealment by vegetation (Gotmark et al. 1995). Nest predation may have been the strong selective force operating on site selection by Semipalmated Plovers because the variables (i.e., pebble substrate with sparse vegetation) selected could reflect antipredator strategies (Graul 1973). Alternatively, nest sites in pebble substrates may provide a surface for retaining heat because eggs placed on pebbles may cool down at a slower rate than eggs placed on bare mud (Reid et al. 2002).

Vertical obstructions in this area generally were low (<20% of cells in our grid were covered), and similar to the general surrounding microhabitat. Habitats were mostly open as found for virtually all other beach or supratidal nesting shorebirds (Nol and Lambert 1984, Olson and Edge 1985, Lauro and Nol 1995). Nesting in relatively open habitat may provide good visibility to facilitate: (1) detection of a nest predator from the nest, (2) conspecific communication, and/or (3) detection of prey or foraging conspecifics (Gotmark et al. 1995). Early detection of nest predators is important for defense in plovers because they rely on crypsis (Graul 1973) and distraction displays to prevent nest predation (Nol and Blanken 1999). Territory defense against foraging conspecifics also may be facilitated if nests were not fully hidden.

The main component of PC2 that varied between nest and random sites was the small proportion (<6%) of bare mud in the nest quadrat, suggesting that plovers may be avoiding sites with a large proportion of muddy substrate. Nests placed in bare mud remain exposed, whereas nests placed in pebble substrates may be concealed because of the cryptic pigmentation of plover eggs. This may be relevant because sympatric Arctic geese (Canada Geese, *B. canadensis*, and Snow Geese, *Chen caerulescens caerulescens*) have overgrazed soil-binding vegetation on western parts of Akimiski Island, resulting in a transition from sub-Arctic coastal salt marsh to extensive denuded areas (Srivastava and Jefferies 1996). This may reduce the sand-gravel depositional areas preferred by plovers through tidal flooding. The degree to which Arctic geese impact nest site availability of shorebirds throughout the eastern Arctic deserves further study.

Selection of nonrandom sites for nest placement suggests long term natural selection on choice of nest sites. Although our results showed that none of the habitat variables were strong predictors of nest success, diverse predators occur in our study. Potential predators of either eggs or young included the American Crow (*Corvus brachyrhyncos*), Common Raven (*C. corax*), Herring Gull (*Larus argentatus*), Peregrine Falcon (*Falco peregrinus*), red fox (*Vulpes vulpes*), shorttail weasel (*Mustela erminea*), and striped skunk (*Mephitis mephitis*). Nest searching techniques, and the ability to detect nest site patches, vary substantially among these predators so that no single set of habitat characteristics may offer complete pro-

tection (Chase 2002). Clear associations between nest site characteristics and nest success are difficult to demonstrate without experimental manipulations (Colwell and Oring 1990, Chase 2002). Semipalmated Plovers appear to benefit substantially from the protection against predators afforded by the aggressive nest defense behavior of Arctic Terns on Akimiski Island. Thus, this species may be added to the list of shorebirds that, at least sometimes, choose to nest in colonial bird colonies to exploit this advantage (Dyrcz et al. 1981, Burger 1987, Powell 2001). The degree to which plovers alter their timing of breeding to coincide with that of nesting terns currently is under study.

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