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SHORELINE HABITAT USE OF BLACK OYSTERCATCHERS BREEDING IN PRINCE WILLIAM SOUND, ALASKA

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Abstract.—To guide habitat acquisition for species negatively affected by the *Exxon Valdez* oil spill, I quantified habitat use of Black Oystercatchers (*Haematopus bachmani*) breeding in Prince William Sound, Alaska. I used local counts of breeding pairs and Sound-wide transect counts of individuals to determine shoreline features that explained variation in oystercatcher density. Density of pairs, and occurrence of individuals, was greater in areas dominated by shorelines of gradual slopes than in areas dominated by steep shorelines. Within areas dominated by steep, rocky shorelines, breeding density increased as the proportion of mixed sand and gravel beaches and as the number of rocks and small islands increased. Shoreline features that explained variation in local pair density were corroborated by data from Sound-wide surveys. I incorporated information from other studies to construct a general, qualitative decision-tree model that predicts that disturbance-free shorelines of gradual slopes should support the highest densities of breeding Black Oystercatchers. Qualitative and quantitative models should be tested to determine their applicability to shoreline habitat throughout the oystercatcher's range.

USO DE HÁBITAT DE ORILLA DE PLAYA POR PARTE DE INDIVIDUOS DE *HAEMATOPUS BACHMANI*, REPRODUCIÉNDOSE EN PRINCE WILLIAM SOUND, ALASKA.

Sinopsis.—Para construir una guía de adquisición para especies negativamente afectadas por el derrame de petróleo del buque Exxon Valdez, cuantifiqué el hábitat utilizado para la reproducción por parte del ostrero *Haematopus bachmani* en Prince William Sound, Alaska. Utilicé conteos locales de parejas reproductivas, y transectos para conteos de vocalizaciones, para determinar las peculiaridades de la playa que explicaran variación en la densidad de los ostreros. La densidad de parejas y presencia de individuos fue mayor en áreas dominadas por playas con declives graduales, que en áreas dominadas por declives pronunciados. Entre áreas dominadas por terrenos escarpados en playas rocosas, la densidad de parejas reproductivas incrementó en proporción a la presencia de playas de arenas mixtas y gravillosas y con el incremento en el número de rocas y de pequeñas islas. Las peculiaridades de las playas que explicaron la variación en la densidad de parejas se corroboraron con los datos tomadas de los transectos. Incorporé información de otros estudios para construir un modelo cualitativo para tomar desiciones, que predijó que las playas libres de disturbios y de declive gradual mantienen las densidades más altas de ostreros. Los modelos cuantitativos y cualitativos deben ser puestos aprueba para determinar su aplicabilidad para determinar el hábitat más adecuado para el ostrero a lo largo de su distribución.

The Black Oystercatcher (*Haematopus bachmani*) is an inhabitant of rocky shorelines along the Pacific coast of North America (Hayman et al. 1986, Paulson 1993). Its southern range limit coincides with a transition from rocky shores to sandy beaches in Baja California (Jehl 1985), and individuals are absent from sandy or muddy shorelines in the Pacific Northwest (Paulson 1993). Besides nesting on solid, rocky substrates of boulders and small islands (Paulson 1993), breeding Black Oystercatchers nest and forage on gravel and cobble beaches (Andres and Falxa 1995, Lentfer and Maier 1995). In British Columbia, flocks also forage on sand

and gravel tidal flats during the winter (Hartwick and Blaylock 1979). Because oystercatchers depend on marine coastlines throughout their annual cycle, they are susceptible to shoreline disturbances and concern about the conservation of Black Oystercatchers has been raised (Carter et al. 1996).

After a preliminary assessment of data collected in 1989 (Klosiewski and Laing 1994), the Black Oystercatcher population inhabiting Prince William Sound, Alaska, was determined to have been negatively affected by oil spilled from the *T/V Exxon Valdez.* Oil that washed ashore killed adults and negatively affected their reproduction (Andres 1997). The *Exxon Valdez* Oil Spill Trustee Council (1991) identified acquisition and restoration of shoreline habitat as possible actions to aid recovery of species negatively affected by the spill. A knowledge of a species' habitat requirements was needed, however, before such restoration actions could be initiated, and habitat use of Black Oystercatchers had not been evaluated on more than a local level. Therefore, I quantified habitat use of oystercatchers breeding in the Sound and constructed a general model of Black Oystercatcher habitat use.

STUDY AREA AND METHODS

Ringed by mountains exceeding 3960 m, Prince William Sound, Alaska (approximately 60°30′N, 147°00′W), encloses the northernmost waters of the Gulf of Alaska. Convoluted shorelines, deep fjords (maximum water depth >870 m), and numerous islands characterize the Sound. Shoreline habitats range from tidal flats of low wave-energy to steep, rock walls of high wave-energy. Shorelines are influenced by a large amplitude, diurnal tide (mean range = 3.8 m). Summers are cool and winters are moderate; mean annual temperatures range from 2.1–4.5 C among areas of the Sound. All seasons are wet and windy; mean annual precipitation ranges from 158–445 cm. Uplands are dominated by rock cliffs, bogs, and forests of western hemlock (*Tsuga heterophylla*) and Sitka spruce (*Picea sitchensis*). Most uplands surrounding the Sound lie within the boundaries of the Chugach National Forest.

I conducted field work along >600 km of shoreline in the vicinity of Green, Montague, and Knight Islands from 1991 to 1993 (Fig. 1). From 15 May–31 July, two- or three-person crews searched shorelines by boat or on foot to determine the presence of breeding pairs. When nest sites were found, their locations were mapped on 15-min topographic maps. Shorelines were resurveyed every 10 d during all 3 yr to locate nesting pairs. To estimate density and assess its relationship to shoreline features, I partitioned the study area into natural geographic units (e.g., by points and bays) and used the maximum number of pairs occupying the unit in any of the 3 yr to calculate density (pairs/km) in each unit.

I used the literature and my field impressions to select three habitat features that I thought would be correlated with oystercatcher density: shoreline slope, shoreline type, and density of islets. Designations of shoreline types were taken from maps generated by the *Exxon Valdez* Oil

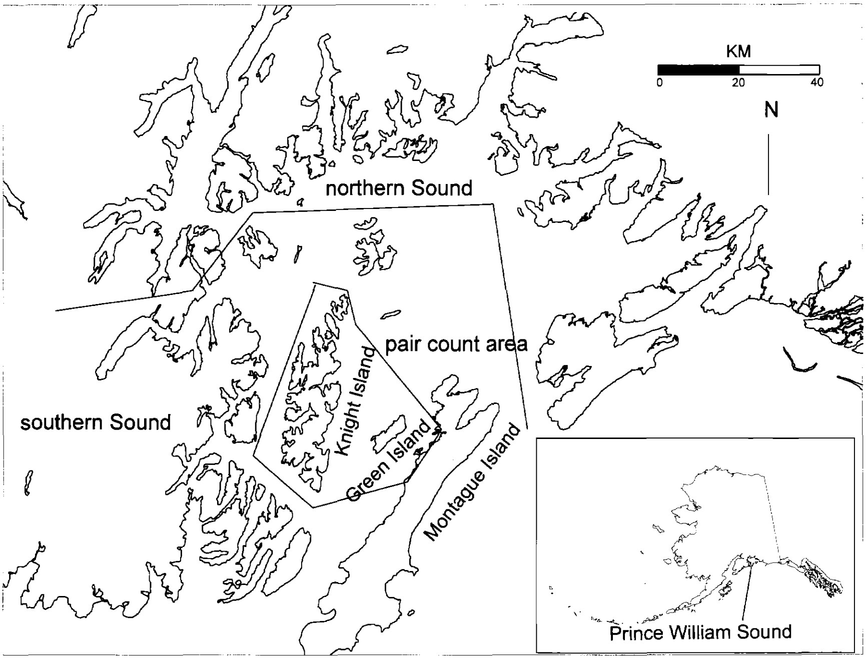

FIGURE 1. Location of Black Oystercatcher study area on Green, Montague, and Knight Islands and designation of the northern and southern areas and pair count area in Prince William Sound, Alaska.

Spill Damage Assessment Geoprocessing Group (unpubl. data), and proportions of the following types were calculated for each geographic unit: exposed wave-cut platforms, exposed rocky, sheltered rocky, gravel, mixed sand and gravel, and tidal flats. Tidal flats were restricted to a few areas on Green and Montague Islands and were similar in composition to mixed sand and gravel beaches and treated as such.

As an index to shoreline slope, I used 15-min topographic maps to measure the maximum shoreline elevation, within 0.3 km perpendicular to the shoreline, at points where each 1.609-km (1-mile) section-line intersected waters of the Sound. Only section-lines >0.3 km apart were included in the sample. As an indicator of nest site availability, I counted the number of islets (offshore rocks and islands <100 m in diameter) present within 0.3 km of the shore in each geographic unit.

I used Manly's (1991) two-sample randomization procedure to test for differences (D) in oystercatcher density between major island groups (Knight vs. Green/Montague). The number of iterations performed in each randomization test was set at 5000 iterations. I used linear regression analysis to evaluate shoreline predictors of oystercatcher density; linear model-checking procedures involved visual inspection of residuals plotted against predicted values, correlation of residuals and predicted values, and calculation of Cook's D and tolerances. Explanatory variables in linear regression models were not correlated and hence did not violate assumptions of independence, and data did not violate assumptions of fitting a linear model.

To validate habitat models generated from counts of breeding pairs made in the Knight and Green/Montague Island vicinity, I analyzed transect counts of oystercatchers made on Sound-wide boat surveys during the breeding season (July). Boat survey procedures involved counting all oystercatchers observed on a set of randomly selected shoreline transects, located ≤ 100 m from shore, distributed throughout the entire oiled (in 1989) and unoiled area of the Sound (approximately 5000 km^2). I excluded, however, any transect that overlapped with the pair-count study area (Fig. 1). Although transect lengths varied between 2.5 and 15.8 km, no relationship existed between transect length and the number of birds encountered. Therefore, a weighted estimator of oystercatcher density, or occurrence, was not used (Klosiewski and Laing 1994). Sound-wide transects, and pair counts, were distributed proportionally among oiled and unoiled areas; thus, shoreline oiling should not confound interpretation of habitat features important to oystercatchers. Procedural details of boat surveys are provided in Klosiewski and Laing (1994) and Agler et al. (1994). I included transect counts from 1990, 1991, and 1993 in the analysis, but did not include counts from 1989 due to reduced survey effort and high shoreline disturbance.

Because of differences in oystercatcher density and shoreline habitat between Green/Montague and Knight Islands (see Results), I classified the slope of each shoreline transect in the northern area of the Sound as gradual or steep (Fig. 1). Shorelines of gradual slope were those where the elevation within 0.3 km of the shoreline did not reach the 62-m contour along at least 33% of the transect, and shorelines of steep slope were those where the elevation exceeded 62 m within the same bounds. Within this area, I compared oystercatcher density between transects in areas of steep shorelines and those in areas of shorelines that had gradual slopes. Information on specific shoreline type was not available for transects in the northern area of the Sound.

Based on information gathered on Knight Island (see Results), shoreline type and counts of islets were determined for transects in the southern Sound as described above (shoreline types were available for the southern Sound). Because no birds were seen on many transects, I used nonlinear regression (Probit model, where $y = 0.1$; Agresti 1990:102–104) to test for a relationship between habitat variables and the occurrence of Black Oystercatchers on transects. Explanatory variables used in this model were not correlated, and inspection of residuals yielded no violation of model assumptions.

RESULTS

Shoreline slope differed markedly between Knight Island and Green/Montague Islands (Table 1). Shoreline types with gradual slopes on

TABLE 1. Shoreline characteristics of Knight and Green/Montague Islands and density of breeding pairs of Black Oystercatchers, Prince William Sound, Alaska, 1991–1993.

	Green/Montague	Knight
Total km of shoreline surveyed	109	499
Mean no. of islets (per km)	15.0	22.9
Mean elevation (m) within 300 m	34	144
Shoreline types (%)		
Exposed/sheltered rocky	0.2	61.6
Wave-cut platforms	27.4	6.6
Gravel beaches	34.8	5.2
Mixed sand and gravel beaches	35.7	26.2
Mean breeding pairs per km (*n*)	0.63 (69)	0.08 (40)

Green/Montague Islands consisted of exposed wave-cut platforms, mixed sand and gravel beaches, and tidal flats (63% of all shoreline), whereas shorelines with steep slopes on Knight Island consisted largely of exposed rocky and sheltered rocky types (62%). Consequently, the density of breeding oystercatcher pairs on Green/Montague Islands was a magnitude higher than the density on Knight Island (Table 1). This difference in oystercatcher pair density between island areas dominated by gradual shorelines and those dominated by steep shorelines was corroborated by Sound-wide boat survey data. In the northern Sound, density of oystercatchers on transects located along gradual shorelines ($\bar{x}$ = 0.32 bird/km, n = 20) was significantly greater (randomization test, D = 0.28 bird/km, P = 0.001) than oystercatcher density on transects located along steep shorelines ($\bar{x}$ = 0.04 bird/km, n = 20). Thus, shoreline slope explained broad differences in oystercatcher density.

To further examine habitat features that explain variability in oystercatcher density in areas dominated by steep shorelines (which is typical of the Sound), I used the density of islets and the proportion of mixed sand and gravel beaches to predict breeding pair density on Knight Island. Mixed sand and gravel beaches tended to have gradual slopes and often occurred in small patches along the shoreline. Breeding pair density within geographic units increased (Table 2; linear regression, F = 26.8, P = 0.001, n = 14, R^2_{adj} = 0.80) as the proportion of mixed sand and gravel beaches (t = 3.69, P = 0.004) and density of islets (t = 7.24, P = 0.001) increased. The density of islets alone (t = 4.44, P = 0.001) was a good predictor of oystercatcher density (linear regression, F = 19.7, P = 0.001, n = 14) but explained less of the variation in density than did the three-parameter model (R^2_{adj} = 0.59).

Data from random boat-survey transects in the southern Sound, an area dominated by steep shorelines, supported results generated from pair count information collected on Knight Island. The proportion of mixed sand and gravel beaches (Wald's χ^2 = 4.33, P = 0.037) and the density of islets (Wald's χ^2 = 6.06, P = 0.014) were significant predictors of oys-

TABLE 2. Parameter estimates and standard errors for proportion of gradual shoreline and islet density (islet) and standard errors of predicted values (SE[ȳ]) for Knight Island and Sound-wide models of breeding Black Oystercatcher density, 1990–1993.

Model	Variable	Coefficient	SE (coef.)	SE (ȳ)
Knight Island pairs-linear	constant	−0.053	0.024	0.029
	gradual	0.206	0.056	
	islet	0.049	0.007	
Knight Island pairs-linear	constant	0.018	0.020	0.042
	islet	0.040	0.009	
Sound-wide counts-Probit	constant	−0.930	0.296	—
	gradual	1.099	0.528	
	islet	0.210	0.085	

tercatcher occurrence (nonlinear regression, $\chi^2 = 9.18$, df = 2, $P = 0.01$; Table 2; $n = 91$) along transects.

DISCUSSION

Sound-wide information from boat survey transects validated predictions from local pair counts that (1) densities of breeding Black Oystercatchers would be higher in areas dominated by shorelines of gradual slopes than in areas dominated by steep shorelines, and (2) densities in areas dominated by steep shorelines would increase as the density of islets and the proportion of mixed sand and gravel beaches increased. In other portions of their range, local densities of breeding oystercatcher pairs are highest on small (<5 km circumference), flat islands: 4.6 pairs/km on Destruction Island, Washington (Nysewander 1977), 14.0–22.8 pairs/km on Cleland Island, British Columbia (Vermeer et al. 1992a), and 10.8–53.5 pairs/km in Glacier Bay, Alaska (Lentfer and Maier 1995). The highest local density on a small, flat island in the Sound was 6.6 birds/km on Channel Island. These results suggest wide-spread applicability of my habitat predictors.

The gradual slopes of wave-cut platforms, gravel beaches, tidal flats, and mixed sand and gravel beaches expose a greater surface area for foraging than do steep, rocky shorelines, and render more prey available to oystercatchers at any time during a low tide. In areas of steep shorelines, high densities of islets appear, from nautical charts, to indicate shallow water depths that would expose a greater amount of foraging area for oystercatchers at low tides. Indeed, Black Oystercatchers use gradual, gravel shorelines for foraging sites. Adults made more foraging commutes to mixed sand and gravel beaches than other shoreline types, and blue mussel (*Mytilus trossolus*) density along beaches where oystercatchers foraged was three times greater than mussel density along adjacent, steep shorelines where they did not forage (Andres 1996).

In areas of dominated by steep shorelines, pairs often use islets as nest sites. Most nest sites used by pairs on Knight Island were located on islets (80%, $n = 56$), whereas most nest sites on Green/Montague Islands, an area dominated by gradual shorelines, were located on points or along straight shoreline sections of the main islands (97%, $n = 79$). The high use of islets as nest sites by breeding pairs suggests that oystercatcher density in areas dominated by steep shorelines may be limited by the presence of islets that are appropriate for nesting; gravel outwashes of avalanches provide the only other type of nest site available to oystercatchers on Knight Island.

Besides shoreline characteristics, other factors may influence habitat use by breeding Black Oystercatchers. Predation on eggs and young is probably a strong selective force for nesting on islets (Hartwick 1974, Nysewander 1977, Campbell et al. 1990) and may contribute to local patterns of distribution among shoreline habitats. Negative effects of human or feral animal disturbance on breeding pairs are also well documented. Although disturbance by humans and domestic animals precluded Black Oystercatchers from nesting on South Farallon Island, California, for 100 yr, 20 pairs reestablished territories within 5–7 yr after major disturbances were eliminated (Ainley and Lewis 1974). A similar response was noted on Destruction Island, Washington, where oystercatchers increased from 4–12 pairs within 7 yr of lighthouse automation (Nysewander 1977). Increased human activity around Sitka, Alaska, was thought to have contributed to a decline from 102 individuals in 1940 to 4 individuals in 1985 (J. D. Webster, pers. comm.).

Black Oystercatchers may be absent from otherwise suitable shorelines because of the presence of introduced Arctic foxes (*Alopex lagopus*) and red foxes (*Vulpes vulpes*). In the Aleutian Islands, Alaska, occurrence of Black Oystercatchers is a good indicator of the absence of foxes (E. Bailey, U.S. Fish Wildl. Serv., pers. comm.). Although previously absent as breeders, Black Oystercatchers nested along shorelines of the Shumagin Islands the first year after foxes were removed from the islands (Byrd et al. 1996).

Suitable shoreline on Knight Island might have been unoccupied by breeding pairs because of high predator densities; Common Raven (*Corvus corax*) density was much higher on Knight Island than on Green Island (Andres 1996). Colonies of large *Larus* gulls can also affect oystercatcher population dynamics and habitat use. On Cleland Island, British Columbia, a recent increase in the number of Glaucous-winged Gulls (*L. glaucescens*) has been coupled with a decrease in the number of breeding Black Oystercatchers (Vermeer et al. 1992b). Black Oystercatcher pairs in the Sound either avoided nesting around Glaucous-winged Gull colonies (>5 gull pairs) or never raised a successful brood when they did nest nearby. All gull colonies within my study area were in the vicinity of Knight Island.

Because numerous factors can influence habitat use by Black Oystercatchers, I used information on shoreline characteristics from my study and information on shoreline disturbance from other studies to develop a qualitative, decision-free model of potential breeding habitat (Fig. 2). The difficulty in measuring predator populations precluded me from including this factor in the model. Most likely, natural predators affect re-

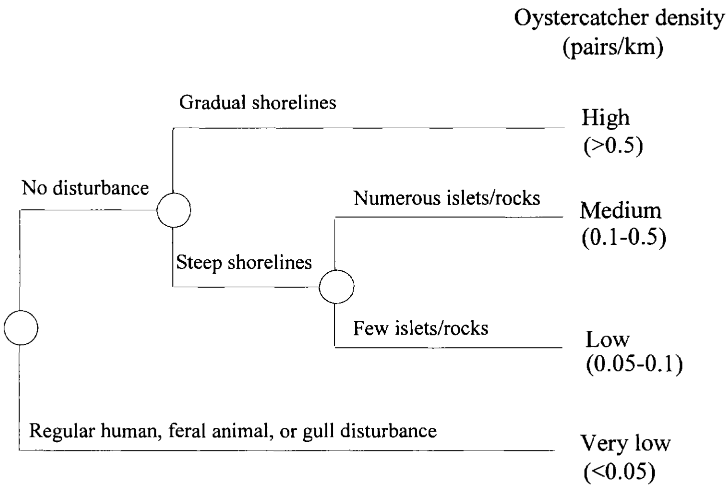

FIGURE 2. Qualitative decision-tree model to assess potential Black Oystercatcher breeding habitat in Prince William Sound, Alaska.

productive success and duration of occupancy by pairs along shoreline segments but not oystercatcher's initial choice of breeding sites. Ultimately, disturbance-free, gradual shorelines that have low natural predator populations should support the highest density of breeding oystercatchers. In areas of steep, undisturbed shoreline, the greatest number of oystercatchers should occur along segments that have a high proportion of mixed sand and gravel beaches and numerous islets. Based on densities in the Sound, I have included ranges of oystercatcher densities for each outcome. For use in areas outside the Sound, density ranges may have to be adjusted to reflect local oystercatcher abundance. The qualitative decision model, and quantitative regression models, should apply throughout the oil spill area and will likely apply to all coastal areas of southeastern and southcentral Alaska. These models could be further validated by information collected in all areas along the Pacific coast of North America.

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