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Research Article

Piping Plover Habitat Selection and Nest Success on Natural, Managed, and Engineered Sandbars

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ABSTRACT Loss of breeding habitat and nest predation have contributed to the decline of many shorebird species. The United States Army Corps of Engineers (USACE) initiated a piping plover (*Charadrius melodus*) habitat creation and augmentation program on the Missouri River in the summer of 2004. The USACE increased unvegetated sandbar habitat by depositing dredged material (engineered sandbars) and by clearing vegetation from existing sandbars (managed sandbars). We evaluated the effects of this increase in nesting and foraging habitat on habitat selection and nest daily survival rate (DSR) of piping plovers on Lewis and Clark Lake and the Gavins Point Reach of the Missouri River from 2005 to 2007 ($n = 623$ nests). Piping plovers selected engineered sandbars more often than expected based on area and selected natural and managed habitats less than expected based on area. Daily survival rate on engineered sandbars was significantly higher than on natural or managed sandbars (log odds: 2.50, 95% CI: 1.05–5.94). Thus, plovers' habitat selection may have increased their nesting success. Our results suggest that habitat augmentation may stave off declines in piping plover populations limited by insufficient habitat and low nesting success.

KEY WORDS *Charadrius melodus*, habitat creation, habitat selection, Missouri River, nest success, piping plover, shorebird.

Understanding the factors that affect habitat selection and nest survival is required to comprehend the population dynamics of imperiled birds and to implement effective conservation strategies for those species (Martin 1993, Chalfoun and Martin 2007, Clark and Martin 2007). Habitat changes have contributed to the decline in avian nest success through the increase in predation associated with marginal habitats (Tewksbury et al. 2006). The primary cause of nest failure for many shorebirds is predation (Dowding and Murphy 2001, Conway et al. 2005, Isaksson et al. 2007, Smith et al. 2007).

High predation rates often are a symptom of other problems such as habitat loss or degradation (Powell and Collier 2000, Yasué et al. 2007), increased human population, or introduced species (Dowding and Murphy 2001). Short-term measures such as predator control or exclusion may stop or reverse population declines temporarily, but these gains may be insignificant without long-term solutions that address the root problems (Johnson and Oring 2002). Habitat creation or modification may be a necessary response to declining habitat for some populations (Erwin et al. 2003).

As in all management efforts, the efficacy of habitat management should be assessed, and the fitness consequences for affected species should be evaluated. For example, use of restored habitat may be counterproductive if colonizing animals suffer reduced fitness due to low reproductive output or survival (Gates and Gysel 1978, Weldon and Haddad 2005). If there are unnatural stresses (such as increased predation) in these habitats, then habitat selection may not reflect the fitness value of the habitat. For managed or created habitat to be an effective conservation tool, it must both attract the species of interest and allow birds to achieve nesting success, and eventually fitness, that is at least comparable to the habitat that it is replacing or augmenting.

The piping plover (*Charadrius melodus*), a federally threatened and endangered species (United States Fish and Wildlife Service [USFWS] 1985), nests on the Missouri River on sparsely vegetated sandbars and lakeshores (Prindiville Gaines and Ryan 1988, Espie et al. 1996). Sandbars are created when the river transports and then deposits sand. Decreased water flows caused by dams have decreased creation of new sandbars (Jacobson et al. 2009). Moreover, habitat has been reduced by erosion and vegetation encroachment, which have reduced sandbar size and rendered some parts of sandbars unsuitable for plovers (USFWS 2003). Predation of nests and chicks also has contributed to the plover decline (USFWS 2003).

United States Army Corps of Engineers (USACE) management aimed at increasing productivity on Missouri River sites includes habitat creation and management,

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predator control, symbolic fencing (single strand of twine to discourage human trespass), and erection of predator exclosures. We studied the effects of habitat creation and habitat management by observing plover habitat selection and by comparing the success of plovers nesting on these habitat types. Our objectives were to determine 1) if piping plovers selected newly created and managed sandbars more than expected based on availability and 2) if nest survival differed among natural, managed (by vegetation removal), and engineered sandbars.

STUDY AREA

We studied piping plovers on approximately 95 km of the Missouri National Recreational River below the Gavins Point Dam (42° 51′ N, 97° 29′ W) in 2005–2007. The Gavins Reach below the dam (hereafter Gavins) was one of the last free-flowing, unchannelized portions of the Missouri River. Piping plover habitat consisted of sandbars largely unconnected to shore. Much of the habitat available for nesting piping plovers resulted from sand deposited in high flows during the 1990s. The size and composition of sandbars varied widely. Some were low unvegetated mud and sandflats, whereas others were high sandbars dominated in some areas by cottonwood (*Populus* sp.) and willow (*Salix* spp.) saplings (LeFer 2005). Through the breeding season, herbaceous plants grew along the shorelines of most sandbars (LeFer 2005).

In 2004, to restore habitat for piping plovers and least terns (*Sterna antillarum*), the USACE created 3 sandbar complexes using a mixture of dredging and other mechanical methods (such as moving sediment with a bulldozer). In general, the engineered sandbars were longer (in the direction of river flow; $\bar{x} = 616$ m, SE = 288 m) than wide ($\bar{x} = 242$ m, SE = 96 m), and in 2005, the 3 sandbars were 6.8 ha, 20.6 ha, and 20.7 ha, respectively. In 2007, we included a newly created sandbar complex on Lewis and Clark Lake (hereafter the Lake). The Lake was a reservoir impounded by the Gavins Point Dam, and the sandbar complex was created within the upriver portion of the Lake. The 2 sandbars in this complex were less elongate (lengths: 520 m and 552 m; widths: 303 m and 330 m) than those built in the river and encompassed 27.3 ha.

The USACE also managed natural habitat by spraying herbicide (typically in early fall or late winter) and cutting vegetation with brush-axes (229.1 ha and 287.9 ha were sprayed and mowed in 2005 and 2006, respectively). The cut vegetation was usually not removed, so managed habitats often were a mixture of open dry sand patches and areas where cut vegetation and short stems were the primary ground cover. Managed habitats, however, varied widely in their treatments and appearance from year to year. The USACE sprayed some sandbars without cutting the vegetation, sprayed and cut the vegetation (leaving the refuse in place) on some sandbars, and sprayed, cut, and burned the refuse in piles on other sandbars. Of 16 sandbar complexes in the study, 3 were managed in some way in 2005, and 3 others were managed in 2006. The sandbars we selected for study encompassed all engineered habitat, and we selected additional sandbars based on historic nesting numbers as well as activity patterns of piping plovers in the preseason of 2005. The USACE monitoring crews, responsible for all habitat on the river, indicated that our sampled sandbars encompassed 70–78% of the breeding population of piping plovers on the Gavins Point Reach (G. Pavelka, USACE, unpublished data). Thus, of the 16 sandbar complexes in our study, 4 were engineered, 6 were natural throughout the study, and 6 were naturally created, but managed at some time during our study.

The primary cause of nest loss in our study appeared to be predation, but nests also were lost to flooding, bank erosion, abandonment, and trampling by various species. Potential nest predators in this region included coyotes (*Canis latrans*), raccoons (*Procyon lotor*), American mink (*Mustela vison*), and American crows (*Corvus brachyrhynchos*).

METHODS

Throughout the nesting season (Apr–Jul), we searched each sandbar for nests by walking transects through potential nesting habitat (unvegetated and sparsely vegetated wet and dry sand habitat) and by watching plover behavior. We recorded nest locations using a handheld Global Positioning System (GPS). In 2005, we floated eggs if we found nests with 3 or 4 eggs (Westerkov 1950; G. Pavelka, USACE, unpublished data). In 2006–2007, we floated ≥ 1 egg from each nest at the time of nest discovery to estimate the incubation stage and timing of nest initiation. We visited nests approximately every other day until failure or hatching ($n = 623$ nests).

Analytical Methods

We measured habitat availability (i.e., total area) using land classification coverages collected during the 2005–2007 breeding seasons (L. Strong, United States Geological Survey [USGS], unpublished data). The USACE collected pan-sharpened multispectral QuickBird satellite imagery (DigitalGlobe, Inc., Longmont, Colorado) each year between April and October and classified it using Definens Developer Software (Definens, Munich, Germany; L. Strong, USGS, unpublished data). We measured the area of unvegetated and sparsely vegetated wet and dry sand habitat and considered this an estimate of the area of piping plover nesting and foraging habitat. We calculated proportion of habitat use as the proportion of nests initiated on each sandbar type within a year. We compared percent area and percent use of sandbar types (i.e., natural, managed, and engineered) using a chi-square test to determine overall selection within each of the years. We compared 95% confidence intervals on proportion of use to availability to determine selection for or against particular sandbar types (Neu et al. 1974, Byers and Steinhorst 1984). We compared habitat selection among years to describe changes in selection over time.

We considered a nest that hatched ≥ 1 chick to be successful. For nests where we never observed chicks, we considered a nest possibly successful if ≥ 1 egg disappeared with no sign of predation within ± 2 days of the estimated hatch date (34 days from nest initiation, Elliott-Smith and

Haig 2004). For the analysis, we right-censored possibly successful nests at the time of last known activity (i.e., we removed data beyond the last known activity). We determined the failure date for abandoned nests by examining visit records and using information regarding presence or absence of adults.

We used a random effects logistic-exposure model (Rotella et al. 2004, Shaffer 2004, Stephens et al. 2005) to estimate the daily survival rate (DSR) of nests in our study ($n = 599$; reduced sample as a result of incomplete information for some nests). The logistic exposure model is a generalized linear model that uses a logit link to relate DSR to the regression:

$$\mathrm{DSR}_i = \frac{e^{\beta_0+\sum_j \beta_j x_{ij}}}{1 + e^{\beta_0+\sum_j \beta_j x_{ij}}}$$

where i represents day, j the covariates, and β_j the coefficient of covariate j (Rotella et al. 2004). By exponentiating the individual β estimates, we produced log-odds ratios that represent multiplicative change in DSR associated with each covariate. In other words, a log-odds ratio of 1.1 for β_1 indicates a 10% increase in the DSR due to the effects of covariate 1. A log-odds ratio estimate is statistically significant if the 95% confidence interval does not include 1.

In addition to the main variable of interest (sandbar type), we controlled for several ecological and management variables in our analysis that could have affected our estimates: predator exclosures (e.g., Johnson and Oring 2002, Isaksson et al. 2007), nest age (Klett and Johnson 1982, Johnson and Walters 2008), number of eggs, nest density (Gunnarsson and Elmberg 2008), date, and interactions between exclosures and other variables (age, date, no. of eggs, nest density, and sandbar type). Additionally, controlling for the dependence of nest fates is an important issue in nest survival studies (Stephens et al. 2005). We included a random effect for a sandbar by year interaction in all of our models under the assumption that fates of nests on the same sandbar in the same year may not be independent.

We tested fit of the global model with a Hosmer and Lemeshow goodness-of-fit test (Hosmer and Lemeshow 1989, Shaffer 2004; $\chi_8^2 = 13.72$, $P = 0.09$). We examined all possible subset models of the above variables, such that we compared models with all combinations of these variables (Montgomery et al. 2001). We ran a correlation analysis of all variables, and the highest correlation was 0.55 (between nest age and date). We concluded that these correlation values were low enough for us to include all variables as controls in our analysis. We analyzed models using PROC NLMIXED (SAS Institute, Inc., Cary, NC), and we used Akaike's Information Criterion, corrected for small sample size (AIC_c) to rank models (Burnham and Anderson 2002). In addition, we used the Akaike's weights to create model-averaged parameter estimates and unconditional standard errors (Burnham and Anderson 2002). We used the model-averaged log-odds ratio estimates to evaluate the differences in DSR among engineered, managed, and natural sandbars. We considered the DSR for the engineered and managed sandbars to be different from that of natural sandbars if the 95% confidence intervals for the model-averaged log-odds ratio estimates did not contain 1.

RESULTS

Piping plovers used all habitat types in proportion to their availability in 2005 ($\chi_2^2 = 2.15$, $P = 0.341$) but used engineered sandbars more and managed sandbars less than expected in 2006 ($\chi_2^2 = 50.32$, $P < 0.001$) and 2007 ($\chi_2^2 = 14.28$, $P < 0.001$; Table 1). Piping plover use of engineered sandbars nearly doubled between 2005 ($n = 73$) and 2007 ($n = 142$), whereas combined use at natural and managed sandbars declined from 2005 ($n = 129$) to 2007 ($n = 72$; Table 1).

Observed nest success rates ranged from 22 to 73% among habitat types and years (mean visit interval from 2005 to 2007 = 2.19 ± 0.01 days, $\bar{x} \pm 1$ SE; Table 2). Nests on engineered sandbars had a 2.5-fold higher DSR than those on natural sandbars (log-odds ratio: 2.50, 95% CI: 1.05–5.94), but nests on managed sandbars showed no difference from natural sandbars (log-odds ratio: 0.82, 95% CI 0.42–1.64). The model-averaged predicted DSR for natural sandbars on the median date in the dataset was 0.98 (95% CI: 0.80–1.00) and for engineered sandbars was 0.99 (95% CI: 0.88–1.00), leading to mean nest successes of 47% and 66%, respectively. All models within 2 $\Delta\mathrm{AIC}_c$ units of the best model included sandbar type as a variable (Table 3), and the cumulative weight of all models containing sandbar type was 0.93.

Table 1. Proportion of use (Pu) of sandbar types for piping plover nesting vs. proportional availability (Pa) on the Missouri River during the 2005–2007 field seasons. We defined proportion of use ($\mathrm{Pu_i}$) as the proportion of nests that were initiated on each type of sandbar within each year and proportion of nesting habitat available ($\mathrm{Pa_i}$) as the proportion of area in each of the sandbar classes in each year.

	Natural sandbars					Managed sandbars					Engineered sandbars				
Yr	n[a]	$\mathrm{Pu_i}$	95% CI	$\mathrm{Pa_i}$	Select[b]	n	$\mathrm{Pu_i}$	95% CI	$\mathrm{Pa_i}$	Select	n	$\mathrm{Pu_i}$	95% CI	$\mathrm{Pa_i}$	Select
2005	87	0.431	0.348–0.514	0.510	=	42	0.208	0.140–0.276	0.193	=	73	0.361	0.280–0.442	0.297	=
2006*	48	0.232	0.162–0.302	0.500	−	31	0.150	0.091–0.209	0.275	−	128	0.618	0.537–0.699	0.224	+
2007*	54	0.252	0.181–0.323	0.384	−	18	0.084	0.039–0.129	0.161	−	142	0.664	0.587–0.741	0.455	+

Years that showed significant ($P < 0.05$) overall selection for or against certain sandbar types from the χ^2 goodness-of-fit test are marked with an asterisk (2005: $\chi_2^2 = 2.15$, $P = 0.341$; 2006: $\chi_2^2 = 50.32$, $P < 0.001$; 2007: $\chi_2^2 = 14.28$, $P < 0.001$).

[a] No. of nests initiated on each sandbar class within each year.

[b] Direction of habitat selection (+ statistically significant selection for, − statistically significant selection against, = no selection).

Table 2. Raw nest success (% total) for piping plover nests on the Missouri River during the 2005–2007 nesting seasons. Known successful nests had ≥1 chick associated with the nest or the parents of the nest. Possibly successful nests did not have chicks associated with the nest or adults but eggs disappeared within 2 days of the projected hatch date. Failed nests did not have chicks associated with the nest or adults and disappeared outside the window of reasonable hatch dates (excluding abandoned nests).

			Known successful		Possibly successful		Failed predation		Failed abandoned		Failed flooding		Failed other[a]		Failed unknown	
Yr	Habitat type	Total nests	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
2005	Natural	76	33	43.4	8	10.5	6	7.9	3	3.9	0	0.0	0	0.0	26	34.2
	Managed	36	12	33.3	2	5.6	12	33.3	2	5.6	0	0.0	0	0.0	8	22.2
	Engineered	71	52	73.2	2	2.8	0	0.0	2	2.8	1	1.4	5	7.0	9	12.7
2006	Natural	47	14	29.8	1	2.1	7	14.9	5	10.6	9	19.1	0	0.0	11	23.4
	Managed	31	7	22.6	1	3.2	8	25.8	3	9.7	1	3.2	0	0.0	11	35.5
	Engineered	127	84	66.1	4	3.1	2	1.6	13	10.2	0	0.0	4	3.1	20	15.7
2007	Natural	54	21	38.9	7	13.0	14[b]	25.9	2	3.7	6	11.1	1	1.9	3	5.6
	Managed	16	6	37.5	4	25.0	4[b]	25.0	1	6.3	0	0.0	0	0.0	1	6.3
	Engineered	141	80	56.7	8	5.7	29[b]	20.6	12	8.5	3	2.1	1	0.7	8	5.7
Total		599	309	51.6	37	6.2	82	13.7	43	7.2	20	3.3	11	1.8	97	16.2

[a] Includes bank erosion, weather events, and nests stepped on by researchers.
[b] Change in protocols led to more failures classified as predation. If eggs were missing before the hatch date and none of the other causes of failure were implicated, we concluded that predation was the cause of failure. The other frequent causes of nest loss, abandonment and flooding, were obvious to observers. Many of the unknown nest losses from 2005 and 2006 were probably as a result of predation.

Table 3. Model ranking for nest survival models for piping plover nests on the Missouri River during the 2005–2007 nesting seasons. We fitted models with all combinations of variables. We show only those models with a difference in Akaike's Information Criterion (corrected for small sample size) from the highest ranking model (ΔAIC_c) $\leq$ 2.0 and the null model (intercept only).

Model[a]	K^b	AIC_c[c]	ΔAIC_c	Wt[d]
Age + age^2 + date + cage + egg + density + sandbar + cage × age + cage × egg + cage × density + cage × sandbar	15	1,842.81	0.00	0.13
Age + age^2 + date + date^2 + cage + egg + density + sandbar + cage × age + cage × egg + cage × density + cage × sandbar	16	1,842.99	0.18	0.12
Age + age^2 + date + date^2 + cage + egg + density + sandbar + cage × age + cage × date + cage × egg + cage × density + cage × sandbar	17	1,843.58	0.76	0.09
Age + age^2 + date + cage + egg + density + sandbar + cage × age + cage × date + cage × egg + cage × density + cage × sandbar	16	1,844.63	1.81	0.05
Intercept only	2	1,977.50	134.69	0.00

[a] Nest success models included several variables: age of nest (in days, age), date, nest exclosure status (cage), number of eggs in nest (egg), nesting density (density), sandbar type (engineered, managed, natural; sandbar), as well as interactions.
[b] No. of parameters in the model. This includes an intercept and a random effect controlling for sandbar × year.
[c] Akaike's Information Criterion, corrected for small sample bias (Burnham and Anderson 2002).
[d] Akaike's wt (Burnham and Anderson 2002).

DISCUSSION

The shift in piping plover nesting from natural and managed sandbars to engineered sandbars through the study suggests that engineered sandbars attracted piping plovers away from natural sandbars, and our nesting success results suggest that plovers nesting on engineered sandbars had higher nest success than those on natural sandbars. Catlin (2009) found that banded birds were more likely to move from natural habitat to engineered habitat than the converse, supporting the conclusion that engineered sandbars were drawing adults from natural and managed habitats. The newly created habitat contained the open dry sand and pebbles, sparse vegetation, and moist sediment zones used by piping plovers on natural habitats (Elliott-Smith and Haig 2004). Similar to the engineered habitat in our study, dredge spoil islands in coastal habitats have been used by several species (Krogh and Schweitzer 1999, Powell and Collier 2000, Collis et al. 2001, Erwin et al. 2003, Spear et al. 2007), showing the potential for replacing or augmenting natural habitat. The long-term value (>4 yr) of engineered sandbars, however, remains to be studied. As the most notable difference between engineered sandbars and natural sandbars was presence of vegetation, it is likely that over time the engineered sandbars will become less desirable as vegetation encroaches. Some vegetation growth already was present by the end of our study, but our results, and those from the banding study (Catlin 2009), indicate that vegetation encroachment was not reducing selection for engineered habitat during our study.

We found no evidence that managed sandbars affected nest survival, but selection against them brings their usefulness into question. Maintenance of dredge spoil islands (i.e., vegetation removal) has been proposed as a means for improving productivity of waterbirds in other studies (Erwin et al. 2003, Spear et al. 2007), but management efforts to improve natural habitat in our study failed, resulting in selection against these habitats and no increase in nesting success. As with the engineered habitat, vegetation was probably one of the driving factors behind our observed selection. Not only was the vegetation removal incomplete in our study (i.e., brush piles and low stems were left on the sandbars), but rapid growth of herbaceous vegetation probably also made these habitats less desirable. The methods used by the USACE during our study, however, are still in the development stage, and more complete removal of vegetation and debris may yet provide suitable nesting habitat for piping plovers on the Missouri River. If successful, vegetation removal could offer a less costly alternative to engineering habitat.

Daily survival rates for piping plover nests in our study (all habitat types, 95% CI on mean predictions from the dataset: 0.979–0.982) were comparable to those for piping plovers elsewhere (range: 0.93–0.99; Prindiville Gaines and Ryan 1988, Patterson et al. 1991, Melvin et al. 1992, Mabee and Estelle 2000, Harris et al. 2005, Ivan and Murphy 2005, Cohen et al. 2009). Low reproductive success often leads to decreased fidelity in adult birds (Greenwood and Harvey 1982, Johnson and Gaines 1990, Gowaty and Plissner 1997, Haas 1998, Catlin et al. 2005), and this tendency may have contributed to our habitat selection results. If piping plovers were reacting to low nesting success by dispersing, we would expect to see selection for engineered habitat as a result of higher fidelity to these sites than to natural and managed natural sites. Both our selection results, and the emigration results from a banding study (Catlin 2009), are in keeping with this prediction, suggesting that greater nesting success on engineered sandbars than on natural or managed sandbars contributed to selection for engineered habitat.

MANAGEMENT IMPLICATIONS

Construction of engineered sandbars may enhance the recovery of piping plovers on the Missouri River. Given that nesting success was higher on engineered habitat than on natural or managed habitats, it appears that engineered sandbars provided higher quality nesting habitat than the other sandbar types. However, raw nest survival declined as engineered habitat aged, suggesting that additional management might be needed to prevent engineered habitat from becoming a sink. These results emphasize an important point about habitat restoration for disturbance-dependent, pioneer species such as piping plovers: spatial and temporal variation in habitat availability may be as important as the amount of habitat available. Such species may be adapted to the formation and disappearance of nesting habitat that occurs unpredictably in time and space. The implications of maintaining nesting habitat for such species in one place over a long period, either through creation or vegetation management, require further study. Managers should consider life-history characteristics such as reliance on disturbance when formulating restoration programs for these species. Finally, habitat selection and nesting success are only 2 metrics by which engineered sandbars should be measured. To fully understand the effects of engineered habitat on piping plover population dynamics, we also must evaluate other measures of productivity, such as chick survival and recruitment, and ultimately population growth.

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