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RESEARCH ARTICLE

Predator exclosures, predator removal, and habitat improvement increase nest success of Snowy Plovers in Oregon, USA

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ABSTRACT

Management to increase reproductive success is commonly used to aid recovery of threatened and endangered species. The Western Snowy Plover (*Charadrius nivosus nivosus*) breeds from coastal Washington, USA, to Baja California, Mexico, and in disjunct interior sites. The Pacific coast population is federally listed as Threatened; habitat loss and nest loss to a suite of terrestrial and avian predators are thought to be primary factors limiting population growth in this species. In coastal Oregon, USA, a consortium of state and federal management agencies deployed nest exclosures on active Snowy Plover nests, initiated a lethal predator management program, and conducted local-scale habitat management in an effort to boost local productivity. During 1990–2009, we monitored 1,951 Snowy Plover nests at 9 sites with varying treatments. We examined the effectiveness of 3 types of nest exclosures (large, small, and outfitted with electric wire), predator removal, and habitat management on nest survival. Habitat management to remove invasive grasses and provide more suitable nesting substrate more than doubled nest survival. Predator management or use of any of the 3 types of exclosures also affected nest survival. There appeared to be no additional benefit to using both approaches, but the biological relevance of these findings is unclear because of site differences in treatments applied. Importantly, these management techniques only affected nesting success; their effect on other contributions to population viability (e.g., fledging success) was not correlated with nesting success. This long-term study illustrates the short-term benefits and tradeoffs of using nest exclosures, predator management, and habitat restoration to improve nesting success. Although we gained broader insight into the relative efficacy of common management techniques to improve avian nesting success, we cannot yet determine how improved nest success contributes to population growth.

Keywords: Charadrius nivosus, exclosure, habitat management, nest exclosure, nest success, nest survival, Oregon, predator, Snowy Plover

La exclusión de depredadores, la remoción de depredadores y las mejoras del hábitat aumentan el éxito de anidación de *Charadrius nivosus nivosus*

RESUMEN

El manejo tendiente a aumentar el éxito reproductivo se usa comúnmente para ayudar a la recuperación de especies amenazadas o en peligro. *Charadrius nivosus nivosus* nidifica desde la costa de Washington hasta Baja California, México, y en sitios disjuntos del interior. La población de la costa pacífico esta listada a nivel federal como amenazada; se piensa que la pérdida de hábitat y la pérdida de nidos causada por depredadores terrestres y por aves son los factores principales que limitan el crecimiento poblacional en esta especie. En la costa de Oregón, un consorcio de manejo de agencias estatales y federales desplegó exclusiones en nidos activos de *C. n. nivosus*, inició un programa de manejo letal de los depredadores y condujo un manejo de hábitat a escala local en un esfuerzo por impulsar la productividad local. Desde 1990 hasta 2009 monitoreamos 1.951 nidos de *C. n. nivosus* en nueve sitios con varios tratamientos. Examinamos la efectividad de tres tipos de exclusiones de nidos (exclusiones grandes y pequeñas, y con cerco eléctrico), de la remoción de depredadores y del manejo de hábitat sobre la supervivencia de los nidos. El manejo de hábitat para remover los pastos invasores y brindar un sustrato de anidación más adecuado duplicó y más la supervivencia del nido. El manejo de los depredadores o el uso de cualquiera de los tres tipos de exclusiones también afectaron la supervivencia del nido. Parece haber un beneficio adicional de usar ambos enfoques, pero la relevancia biológica de estos hallazgos no está clara debido a las diferencias entre sitios en los tratamientos aplicados. Un hecho importante es que estas técnicas de manejo solo afectaron el éxito de anidación; su efecto sobre otras contribuciones a la viabilidad poblacional (e.g., éxito de emplumamiento) no estuvo correlacionado con el éxito de anidación. Este estudio de largo plazo muestra los beneficios de corto plazo y los pros y contras de usar exclusiones de nidos, manejo de depredadores y restauración de hábitat para mejorar el éxito de anidación. Aunque adquirimos una visión más amplia de la eficacia relativa de las técnicas de manejo comunes para mejorar el éxito de anidación de las aves, no podemos aún determinar como la mejora del éxito de anidación contribuye al crecimiento poblacional.

Palabras clave: Charadrius nivosus, depredador, exclusión, exclusión de nidos, éxito de anidación, manejo de hábitat, Oregón, supervivencia del nido

INTRODUCTION

Conservation efforts for threatened and endangered birds often seek to boost reproductive success as a means of increasing overall population growth. There are many published examples of nesting success in birds having been improved by management strategies designed to protect nests (Duebbert and Lokemoen 1980, Rimmer and Deblinger 1990). A critical assumption of this philosophy is that better nesting success translates into better recruitment and population growth. However, few studies have critically examined the long-term benefits of improved nesting success to population growth (Côté and Sutherland 1997, Isaksson et al. 2007, Claassen et al. 2014). Moreover, many studies fail to provide appropriate cautionary comments about the unknown contribution of improved nesting success to population growth, which should be the primary focus of any management action.

In most birds, predation is the primary cause of nest loss (Martin 1993). There are many ways to reduce nest predation, such as placement of nest exclosures directly on nests or the use of electric fencing around nests (Rimmer and Deblinger 1990, Mayer and Ryan 1991, Vaske et al. 1994, Jackson 2001). A second approach, often used in conjunction with exclosures, is the lethal management of specific predators known to prey upon nests, chicks, or adults (Duebbert and Lokemoen 1980, Côté and Sutherland 1997). Alternatively, when lack of high-quality habitat appears to be limiting populations, management efforts may be focused on improving critical nesting habitat (Gratto-Trevor and Abbott 2011). Despite their widespread use, the benefits and costs of each approach are seldom rigorously assessed (Mabee and Estelle 2000, Johnson and Oring 2002, Murphy et al. 2003).

Predator management is a popular approach to increase nest survival in several species of ground-nesting plovers (subfamily Charadriinae) and is believed to aid population recovery in some species (Hecht and Melvin 2009). One approach is to use a nest exclosure, which consists of a structure placed around the nest to deter nest predators (Nol and Brooks 1982). Exclosures vary in size and material, and some include electrical fencing as an added deterrent (Mayer and Ryan 1991). Exclosures are widely used to promote increased nest survival in shorebirds (Mayer and Ryan 1991, Deblinger et al. 1992, Melvin et al. 1992, Vaske et al. 1994, Estelle et al. 1996, Mabee and Estelle 2000, Larson et al. 2002, Murphy et al. 2003b, Neuman et al. 2004). In these studies, exclosures were used as a tool to manage nest losses to predators. The short-term effects of exclosures are well documented; in nearly all studies, they enhanced nest success. However, the long-term benefits of nest exclosures, and other forms of predator management, to population growth are less certain (Côté and Sutherland 1997, Johnson and Oring 2002, Isaksson et al. 2007). Plovers rely on crypsis and early detection of predators to avoid predation; adults stealthily move from nests when a predator is detected. It is possible that exiting an exclosure slows this departure enough that predators are better able to capture the adult (D. J. Lauten and K. A. Castelein personal observation). Exclusion of predators through the use of fences is also possible, though this limits the movement of precocial young (Mayer and Ryan 1991, Rimmer and Deblinger 1992, Moseby and Read 2006). Lethal predator control has been used only sparingly with shorebirds (Parker and Takekawa 1993, Neuman et al. 2004; see summary in Gratto-Trevor and Abbott 2011). The long-term value of predator control is often debated because removal is often followed by a recolonization of the site by predators, which means that some control must be maintained in perpetuity or its benefits will be lost (Côté and Sutherland 1997). Like predator control, habitat management has been used sparingly to increase reproductive success of shorebirds, though its long-term effects are difficult to measure (Maxson and Haws 2000, Marcus et al. 2007, Catlin et al. 2011). Each of the 3 approaches described above has seen some application to conserving plover populations in North America.

The Western Snowy Plover (*Charadrius nivosus nivosus*) breeds along the Pacific coast from Washington, USA, to Baja California Sur, Mexico, and at alkaline lakes in the interior of the western United States (Page et al. 1991). Loss of habitat, predation pressures, and disturbance have caused declines in the Pacific coast population of Snowy Plovers and led to its listing as Threatened in 1993 (U.S. Fish and Wildlife Service 1993, 2006, 2007). Nesting habitat has been lost to coastal development and is also threatened by dune stabilization caused by the exotic European beachgrass (*Ammophila arenaria*). Range-wide recovery efforts have increased breeding populations, but at many sites the fledging rate (a key recovery parameter) remains below the recovery plan's goal of 1 fledgling per adult male per year (U.S. Fish and Wildlife Service 2007), prompting continued intensive management of the species.

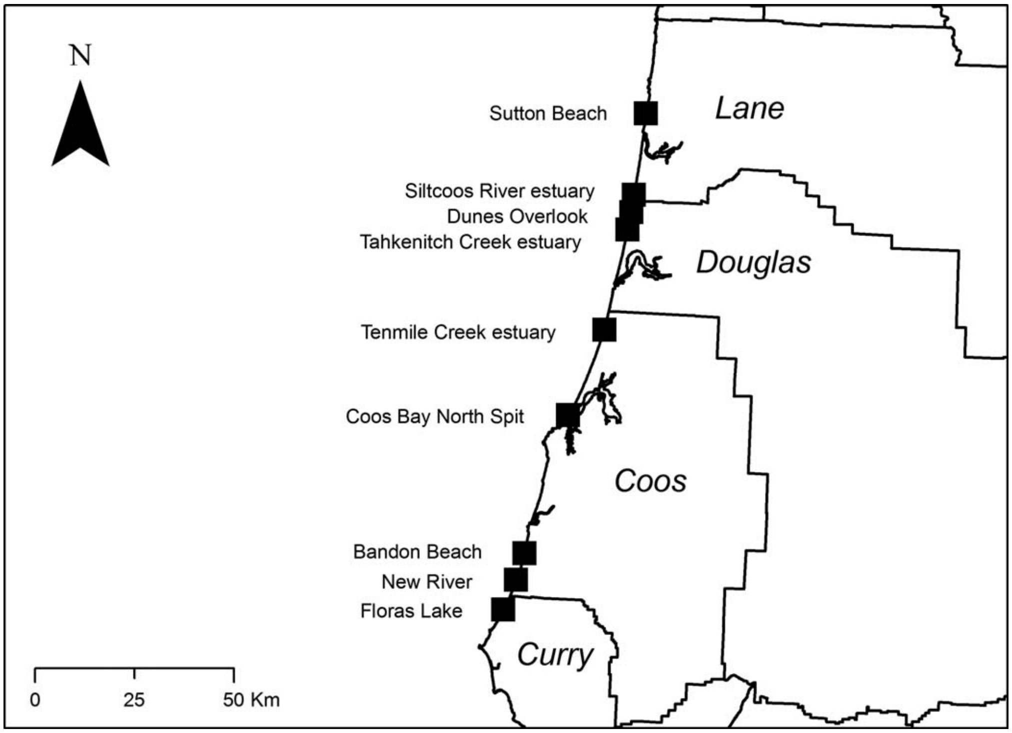

FIGURE 1. Map showing the location of the 9 sites along the central and southern coast of Oregon, USA, where nesting Snowy Plovers were monitored, 1990–2009. County names are in italics, and the 9 sites are labeled with filled squares.

In Oregon, USA, recovery efforts have focused on habitat restoration and maintenance at breeding sites, predator management through both lethal and nonlethal methods, and management of human-related disturbances to nesting plovers (Lauten et al. 2003). This suite of management activities is intended to improve annual productivity, increase Oregon's breeding population, and eventually sustain productivity and population numbers at recovery levels (U.S. Fish and Wildlife Service 2007). Our objectives in the present study were to (1) estimate Snowy Plover nest success; and (2) assess the possible benefits of 3 types of nest exclosures, lethal predator management, and habitat restoration. The large sample of nests, the ability to compare nests between treatments (e.g., exclosed and unexclosed nests), and the long-term dataset make this study unique. Its results are critical to conservation of this threatened coastal shorebird and may be applicable to other beach-nesting species.

METHODS

Study Area

We measured effects of management strategies on Snowy Plover nest success across 20 breeding seasons (1990–2009) in coastal Oregon. We studied breeding Snowy Plovers at 9 sites along the Oregon coast (Figure 1). From north to south, the study sites were Sutton Beach, Siltcoos River estuary, the Dunes Overlook, Tahkenitch Creek estuary, Tenmile Creek estuary, Coos Bay North Spit, Bandon Beach, New River, and Floras Lake; they are described in greater detail in Lauten et al. (2010). These sites represent habitat typical of nesting Snowy Plovers in this region and are composed of open ocean beaches and sand spits, ocean overwash sites within sand dunes dominated by European beachgrass, open estuarine areas with sand flats, and several habitat restoration sites.

Nest Searching and Monitoring

We conducted weekly surveys at all sites from roughly early April through late September, with some variation due to weather and the presence of unusually early or late nests. Field methods followed the approach outlined by Lauten et al. (2003). Briefly, we used searches for incubating adult Snowy Plovers and behavioral cues to locate nests, which we defined as a tangible bowl or scrape with eggs or evidence of eggs (e.g., eggshells). We floated eggs to predict hatch date (Westerskov 1950, G. Page personal communication) and assumed a 29-day incubation period. Nests were monitored weekly, more often near the predicted hatch date, and a "successful nest" was defined as a nest where $\geq$1 egg hatched. Most nesting adults were individually color banded to study site fidelity and annual survival, and each brood was individually color banded to monitor brood success. Adults were captured

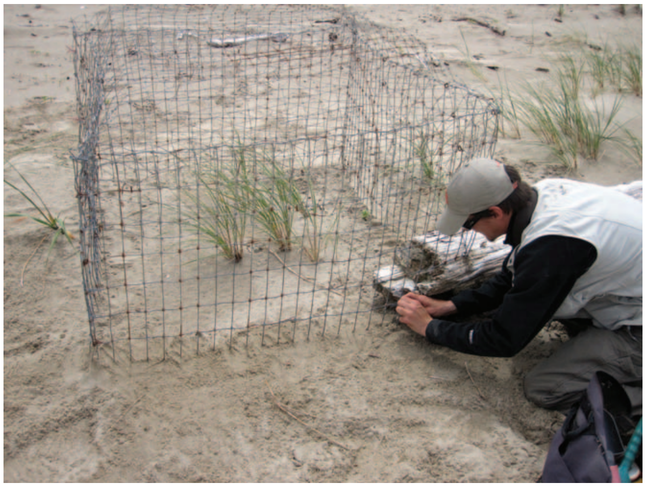

FIGURE 2. Snowy Plover exclosure (Mini design) placed over a 3-egg nest in coastal Oregon. Nests are frequently in the shelter of sparse vegetation or beach debris. Photo credit: Adam Kotaich

using a lily pad trap and noose mats placed around the nest; trapping was limited to a 20-min effort at each nest, to minimize disturbance.

Nest Survival Modeling

We used the nest survival model (Dinsmore et al. 2002) in Program MARK (White and Burnham 1999) to model Snowy Plover nest survival in coastal Oregon. We included in our models the following 7 sources of variation in nest survival.

(1) Nest exclosure type. We evaluated the effects of 3 types of nest exclosures on the survival of Snowy Plover nests: (a) a large wire exclosure with an electric wire along the top (Hotwire), (b) a large wire exclosure without an electric wire (Large), and (c) a more recently designed smaller wire exclosure (Mini) (Castelein et al. 2000, Lauten et al. 2003). All exclosures were constructed of wire mesh, with an opening that was approximately 5×5 cm or 5×10 cm (the latter was most common), which allowed an adult Snowy Plover to walk, but not fly, through it (Figure 2). Avian and most mammalian predators of this species cannot get through the fencing. The fencing did not exclude small mammal predators, including deer mouse (*Peromyscus maniculatus*), short-tailed weasel (*Mustela erminea*), long-tailed weasel (*M. frenata*), and immature striped skunk (*Mephitis mephitis*). Prior to 2001, nests were exclosed as they were discovered. After 2001, exclosures were not deployed until after the peak of raptor migration (approximately May 15) because of concerns that raptors might depredate adults as they exited the structure. Exclosures were used at Sutton Beach (1994–2006; $n = 39$), Siltcoos River estuary (1994–2009; $n = 126$), the Dunes Overlook (1999–2008; $n = 65$), Tahkenitch Creek estuary (1994–2008; $n = 92$), Tenmile Creek estuary (1992–2008; $n = 124$), Coos Bay North Spit (1990–2006; $n = 208$), Bandon Beach (1991–2009; $n = 89$), New River (1991–2009; $n = 233$), and Floras Lake (1991–2009; $n = 42$). Collectively, across all sites and years, 1,018 (52%) Snowy Plover nests received an exclosure, while 933 nests were never exclosed.

(2) Lethal predator management (PM). Lethal management of the principal predators of Snowy Plovers began at some sites in 2002 and expanded to all sites in 2004. Management was done under the appropriate state and federal permits by U.S. Department of Agriculture Wildlife Services personnel. The target species of these efforts were Common Ravens (*Corvus corax*), American Crows (*Corvus brachyrhynchos*), and several species of mammals, including red fox (*Vulpes vulpes*), coyote (*Canis latrans*), striped skunk, and raccoon (*Procyon lotor*), all of which are known predators of Snowy Plover nests in this region (Burrell 2010). Removal was primarily done by trapping, shooting, and use of the avicide DRC-1339 (Little 2009). Effort and the number of animals removed per year varied, but the latter was generally >200 corvids and <30 mammals per year across all sites (Little 2009, M. Burrell personal communication). Because of the variation in annual effort, we used this as a categorical variable only in our analyses.

(3) Habitat restoration (HRA). Habitat restoration efforts began in 1994 as part of the recovery plan and occurred at all sites except Floras Lake. The goal of these efforts was to provide more natural habitat at existing Snowy Plover nesting sites. Habitat Restoration Areas (HRAs) varied in size from 2 to 60 ha; because of this variation and the limited number of sites, we modeled this only as a categorical variable. Treatments occurred during the winter and included bulldozing or hand-pulling exotic European beachgrass, adding oyster shell hash as a nesting substrate, and disking to set back plant succession. Once initiated, site maintenance typically occurs annually at all HRAs. A total of 1,182 nests (61%) were located in habitat restoration areas.

(4) Site. The 9 sites used in our study differed in size, degree of human disturbance, risk of predation by birds and mammals, and other factors. Because we did not collect data to directly address these factors, we chose to include an omnibus site effect in our models to account for these differences.

(5) Year. Annual differences in nest survival can result from many factors, such as weather or changes in the predator community. To account for this variation, we included year effects in our model set.

(6) Seasonal patterns within years. Other studies of the Snowy Plover have demonstrated variation in nest survival within the breeding season (Colwell et al. 2011, Saalfeld et al. 2011, Sexson and Farley 2012), a pattern that also occurs in other plover species (Dinsmore et al. 2002, Toral and Figuerola 2012). Seasonal variation in survival

TABLE 1. Summary of Snowy Plover nesting activity by site and year in coastal Oregon, USA, 1990–2009. Sites were Sutton Beach (SU), Siltcoos River estuary (SI), the Dunes Overlook (OV), Tahkenitch Creek estuary (TA), Tenmile Creek estuary (TM), Coos Bay North Spit (CBNS), Bandon Beach (BA), New River (NR), and Floras Lake (FL).

	Site									
Year	SU	SI	OV	TA	TM	CBNS	BA	NR	FL	Total
1990					2	24		6	2	34
1991						12	14	6	2	34
1992					9	10	8	2	6	35
1993					8	9	7		11	35
1994	1	3		3	7	17	5	6	8	50
1995				1	3	18	8	18	6	54
1996	6	3		19	4	27	3	18	8	88
1997	13	3		14	2	23	4	25	8	92
1998	8	4		6	11	18	1	25	4	77
1999	2	21	2	3	5	14	2	27		77
2000	7	21	8	5	6	27	2	17	5	98
2001	14	14	15	13	8	17	5	22		108
2002	3	10	8	15	12	19	5	14	1	89
2003	1	7	6	13	16	22	5	15		85
2004		11	14	8	17	25	17	24		116
2005		17	16	11	16	28	29	20		137
2006	4	22	10	4	22	32	22	26		142
2007	3	28	15	9	39	35	30	34		193
2008		35	15	5	25	47	27	33		187
2009		22	13	5	46	62	31	38	3	220
Total [a]	63	221	122	134	258	486	225	376	66	1,951

[a] There were 2 nests in 2002 at other sites.

TABLE 2. Summary of Snowy Plover numbers and productivity in coastal Oregon, USA, 1990–2009. Numbers of adults present and adults breeding were determined from detailed surveys and represent a minimum estimate. Fledgling numbers were derived from detailed brood surveys and also represent the minimum known to have survived to fledge age (28 days posthatch). The apparent nesting success for all nests, broken down by those with and without nest exclosures, represent the percentage of the total nests where ≥1 egg hatched.

				Nesting success (%)		
Year	Adults present	Adults breeding	Number of fledglings	All nests	Exclosed	Not exclosed
1990			3	31		28
1991			16	33	75	9
1992			33	67	85	11
1993	72	55	36	68	83	27
1994	83	67	56	75	80	71
1995	120	94	57	50	65	5
1996	134	110	47	56	71	10
1997	141	106	41	48	58	14
1998	97	75	32	56	72	8
1999	95	77	53	56	64	0
2000	109	89	43	38	48	0
2001	111	79	32	35	68	0
2002	99	80	31	44	66	6
2003	102	93	60	51	77	9
2004	136	120	108	62	85	8
2005	153	104	78	48	72	14
2006	177	135	110	47	66	32
2007	181	162	124	42	71	35
2008	188	129	73	34	49	30
2009	199	149	107	33	76	25
Overall				49	68	25

could result from a host of factors, including adult age, differences between first nests and renests, and many others. To account for this, we compared a model with no seasonal variation [.] to models in which within-season variation exhibited a linear [T] or quadratic [TT] pattern. The latter 2 models do not force a specific seasonal pattern (e.g., a peak in midseason), but instead allow the data to suggest a pattern, if one exists.

(7) Clutch size. Clutch size ranges from 1 to 6 eggs in the Snowy Plover (Page et al. 2009), and some have suggested that smaller clutches may indicate lower-quality females that are more vulnerable to predation (Price and Liou 1989, Pasitschniak-Arts et al. 1998, Dinsmore 2008).

We used model selection by second-order Akaike's Information Criterion, corrected for small sample sizes, (AIC_c; Akaike 1973) and the general approach of Burnham and Anderson (2002) to evaluate model effects for inference. We used a hierarchical modeling approach that examined temporal patterns of nest survival first (year effects and within-year patterns of nest survival), then site differences, and finally other covariates (e.g., clutch size and habitat restoration) and the effects of predator management.

RESULTS

We monitored a total of 1,951 nests during the 20-yr study (1990–2009; Table 1). The total number of nests monitored at each site ranged from 63 to 486 and spanned a 153-day nesting season (March 27 to August 26) across all years. Across years, mean nest initiation date was May 30 (SD = 28 days) and mean clutch size was 2.68 eggs (SD = 0.67; range: 1–5 eggs). Apparent nesting success was 47% (921 of 1,951 nests were successful). Losses were primarily due to a suite of predators that included corvids (Common Raven and American Crow) and large mammals (e.g., raccoon), ocean overwash, blowing sand, and unknown causes. Apparent nesting success was greater for exclosed (68%) than for unexclosed (25%) nests; this pattern was evident in every year of the study (Table 2). However, despite this increase in nesting success, fledging rates from exclosed and unexclosed nests did not differ (two-sample t-test with unequal variances, 1990–2009; $t_{20} = -0.92$, $P = 0.37$). Nest abandonment rates were similar between exclosed (56/1018 = 0.055) and unexclosed (63/933 = 0.068) nests. The population size and number of fledglings

TABLE 3. Model selection results for patterns of nest survival of Snowy Plovers in Oregon, USA, 1990–2009. Model effects included study sites (Site), year, linear (T) and quadratic (TT) patterns within years, clutch size (Clutch), habitat restoration efforts (HRA), lethal predator management (PM), the effects of 3 specific types of nest exclosures [Hotwire, Large, and Mini), and a model with a single effect for the presence of any exclosure (Exclosure).

Model effects	AIC_c[a]	w_i	K	Deviance
Site+Year+TT+Clutch+HRA+PM*Exclosure	0.00	0.90	35	5,019.39
Site+Year+TT+Clutch+HRA+PM+Exclosure	4.45	0.10	34	5,025.85
Site+Year+TT+Clutch+HRA+PM+Large	250.46	0.00	34	5,271.86
Site+Year+TT+Clutch+HRA+PM+Mini	258.23	0.00	34	5,279.63
Site+Year+TT+Clutch+HRA+PM+Hotwire	336.88	0.00	34	5,358.28
Site+Year+TT+Clutch+HRA+PM	369.39	0.00	33	5,392.79
Exclosure	553.51	0.00	2	5,638.99
Clutch	595.32	0.00	2	5,680.80
Site+Year+TT	890.33	0.00	30	5,919.75
Mini	989.03	0.00	2	6,074.51
TT	1,005.94	0.00	3	6,089.42
T	1,015.10	0.00	2	6,100.58
Large	1,016.47	0.00	2	6,101.95
Site+Year	1,035.71	0.00	28	6,069.13
Year	1,098.88	0.00	20	6,148.34
Site	1,113.37	0.00	9	6,184.84
Hotwire	1,141.60	0.00	2	6,227.08
PM	1,165.88	0.00	2	6,251.36
No effects	1,169.28	0.00	1	6,256.27
HRA	1,170.79	0.00	2	6,247.11

[a] The AIC_c value of the best model was 5,089.48.

produced generally increased during the study period. We documented 41 adult mortalities associated with the use of nest exclosures, although we have no data on adult mortalities at unexclosed nests for comparison.

Our modeling results yielded a single model with overwhelming support (AIC_c weight = 0.90) and a second, less competitive model (Table 3). Thus, we chose to make inference from the single best model. Collectively, these models all had support from the model set (summed AIC_c weight = 1.0; Table 3). The best model combined the additive effects of site, year, a quadratic seasonal effect within year, clutch size, habitat restoration, and an interaction between predator management and the presence of any exclosure (35 parameters). The less competitive model was identical, except that the effects of predator management and the presence of any exclosure were additive (34 parameters). In the best model, there was strong evidence for site and year differences. In addition, there were strong positive effects of clutch size (β_{Clutch} = 0.79 on a logit scale; 95% confidence interval [CI]: 0.69 to 0.89), habitat restoration (β_{HRA} = 0.23 on a logit scale; 95% CI: 0.05 to 0.41), and the presence of an exclosure of any type ($\beta_{Exclosure}$ = 2.00 on a logit scale; 95% CI: 1.76 to 2.25), and an interaction between predator management and any exclosure ($\beta_{PM*Exclosure}$ = –0.44 on a logit scale, 95% CI: –0.78 to –0.10). Thus, Snowy Plover nest survival increased with clutch size, habitat restoration, and the presence of any exclosure; with predator management, exclosures had no effect. It was the presence of any exclosure, not a particular type of exclosure, that most benefited nest survival.

We used the best model to illustrate the effects of exclosures on Snowy Plover nest survival as a function of site, year, day of season, and the presence of any exclosure. For the Siltcoos River estuary in 1990, we predicted the daily nest survival probability for a 3-egg clutch with and without an exclosure, revealing the strong seasonal increase in survival of nests without exclosures (Figure 3). We also predicted the probability that a Snowy Plover nest would hatch $\geq$1 egg (nest success), by site and with and without an exclosure, for years that we considered to represent poor success (1991; Figure 4A), above-average success (2004; Figure 4B), or typical success (2009; Figure 4C).

DISCUSSION

The number of Snowy Plovers nesting in coastal Oregon has increased since the early 1990s, at least partly because of intensive management efforts that included protecting nests, removing key predators, and targeted habitat restoration efforts. The recovery strategy initially used nest exclosures and then habitat restoration to improve nesting success. Lethal predator management was later implemented as a means of improving fledging success. Biologists believed that predator management would benefit nesting success, but its primary intent was to improve fledging success. As this population increases, it is

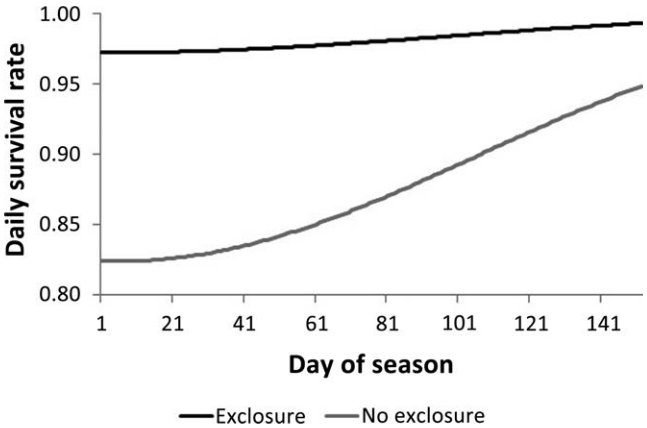

FIGURE 3. Predicted daily survival rates for a Snowy Plover nest containing 3 eggs at the Siltcoos River estuary, Oregon, USA, 1990. The two lines illustrate the effects of seasonal variation in nest survival and the predicted survival difference for exclosed and unexclosed nests.

pertinent to closely examine the benefits and potential tradeoffs of these management efforts. In addition, the long-term nature of our study and its use of multiple management strategies allows for a comparison of the consequences to nest survival within a single population.

Predation of nests and chicks has been identified as an important cause of population decline in the Snowy Plover (Page et al. 1983, Colwell et al. 2005), and mitigating these losses has been the focus of management activities for this species. The use of exclosures on Snowy Plover nests in Oregon resulted in an overall increase in apparent nesting success (68% for exclosed nests vs. 25% for unprotected nests). Our modeling efforts showed a similar response, with protected nests having substantially greater daily survival than unprotected nests. The increase in apparent nesting success for protected nests is consistent with the results of earlier studies of plovers (Rimmer and Deblinger 1990, Melvin et al. 1992, Maxson and Haws 2000, Neuman et al. 2004). In Oregon, Snowy Plovers tend to nest at sites where they have previously succeeded in hatching a nest, regardless of their success in fledging chicks (D. J. Lauten and K. A. Castelein personal observation). Exclosures clearly increase nesting success but may not improve fledging success (Neumann et al. 2004). Exclosures may allow nests to successfully hatch young, but this may be wasted energy if predation results in high levels of chick loss. There is additional concern that exclosures may increase nest abandonment rates, but our study was consistent with Vaske et al. (1994) in finding that abandonment rates did not differ between exclosed and unprotected nests.

Few studies have examined the long-term impacts of nest exclosures on shorebird populations. There is strong support that exclosures improve nesting success, but they require costly maintenance and can increase mortality of

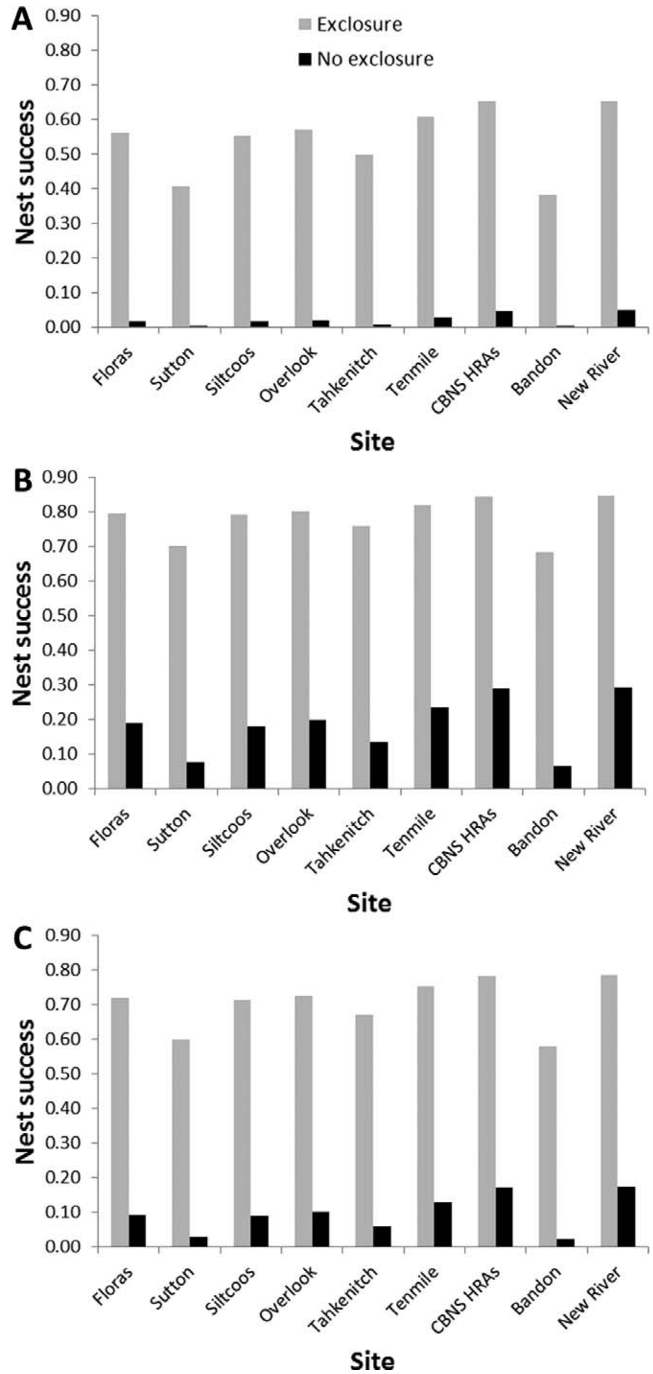

FIGURE 4. Predicted probabilities of surviving the 29-day incubation period for Snowy Plover nests in coastal Oregon, USA. The graphs illustrate differences between sites, exclosed and unexclosed nests, and 3 yr of the study. Study years were (**A**) a poor year (1991), (**B**) a good year (2004), and (**C**) a typical year (2009).

incubating adults. Adult survival may be an important factor driving population growth rate in shorebirds (Larson et al. 2002, Dinsmore et al. 2010), so any adult mortality at exclosed nests could have negative effects on population growth.

Lethal predator management can be an effective tool to increase reproductive success in birds. The primary nest predators must be carefully identified, and control efforts should target only those specific predators. Such targeted management efforts can result in increased survival, as shown with Snowy Plovers in California (Neuman et al. 2004), Piping Plovers (reviewed in Gratto-Trevor and Abbott 2011), and a suite of shorebird species in Scotland (Jackson 2001). However, control measures often must be maintained in perpetuity or the benefits of control will quickly disappear, as shown in studies of waterfowl (Duebbert and Lokemoen 1980, Greenwood 1986). A meta-analysis of 22 bird species found that predator removal had large, positive effects on both nesting success and postbreeding population size, but a nonsignificant effect on subsequent breeding population size (Côté and Sutherland 1997). Our results also suggest that predator control must take exclosure use into consideration; predator management improved nest success at unexclosed nests but did not provide additional benefits to exclosed nests.

Long-term costs associated with predator removal must be weighed against the cost of habitat restoration, which may provide better long-term benefits (Côté and Sutherland 1997). Nests on habitat restoration areas were more successful than those outside of restoration areas. Eight of 9 sites on our study area have received habitat treatments to remove nonnative vegetation and add shell hash. These treatments increase the area of suitable habitat available to breeding plovers and improve nest crypsis, potentially reducing predator nest detection. Similar results have been seen on the Missouri River with Piping Plovers (Catlin et al. 2011). Muir and Colwell (2010) reported that Snowy Plovers nested in sites with significantly less *Ammophila* than random sites, presumably because open sites allow plovers to detect approaching predators earlier.

Snowy Plovers in Coastal Oregon

Collectively, these management efforts (nest exclosures, lethal predator management, and habitat management) have aided the recovery of the Snowy Plover in coastal Oregon. Since 1990, the number of breeding adults has nearly tripled, the number of fledglings has increased (but with increased year-to-year variation), nesting success has benefited from exclosures, and nesting success of unexclosed nests has increased with predator management. Population growth of the Snowy Plover in Oregon is a model success story for this federally listed species. Looking ahead, this population growth has implications for the future use of the management activities we examined, as well as for future allocation of limited resources for monitoring. Monitoring this population of Snowy Plovers is becoming increasingly difficult as the population grows. Habitat management has increased the areas available to Snowy Plovers along the Oregon coast but has also made nest searching more time-consuming—there is more habitat, and, by design, improved habitat makes nests more difficult to find. Some of the adult depredations associated with exclosures have occurred within a short period, causing us to avoid using exclosures at densely populated nesting sites, for fear of losing large numbers of adults. As the population has increased, it has become difficult to use exclosures safely, because nests are more densely packed at some sites, and at others field staff does not have the time to adequately monitor the exclosures. For these reasons, exclosure use has lessened in the past few years. For monitoring, one consequence of reduced deployment of exclosures is that we have fewer opportunities to identify adults associated with nests.

The suite of management actions described here (nest exclosures, lethal predator management, and habitat restoration efforts) helped increase the size of Oregon's Snowy Plover population. We recommend that exclosure use be minimized to prevent unnecessary adult depredations and that they be erected only when there is evidence of persistent corvid or large mammal activity that threatens plover nesting success. We believe that habitat management and predator management continue to be important tools to maintain Snowy Plovers along the Oregon coast.

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