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THE IMPACT OF DIFFERENT PREDATOR EXCLOSURES ON PIPING PLOVER NEST ABANDONMENT

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Abstract.—This paper examines the impact of different types of predator exclosures on Piping Plover (*Charadrius melodus*) nest abandonment. The data were obtained from state or provincial agencies. Of the 211 exclosed nests sampled, only 22 (10%) were abandoned. The impact of three types of independent variables on nest abandonment was evaluated: the process of exclosure construction (e.g., construction time, time elapsed before re-incubation), the design characteristics (e.g., size, shape, construction materials) and geographic location. The exclosure construction process was not related to nest abandonment. Exclosure size, shape, mesh size and fence height were also not significant. The odds of nest abandonment, however, were significantly higher for covered exclosures and those lacking fence posts. In addition, exclosures in northern climes had significantly higher levels of nest abandonment. Design recommendations are suggested for the use of exclosures.

EL IMPACTO DE DIFERENTES BARRERAS PARA DETENER DEPREDADORES EN EL ABANDONO DE NIDOS POR INDIVIDUOS DE *CHARADRIUS MELODUS*

Sinopsis.—En este trabajo se examina el impacto de diferentes barreras para excluir depredadores en el abandono de nidos por parte de individuos de *Charadrius melodus*. Los datos fueron obtenidos de agencias estatales o provinciales. De una muestra de 221 nidos protegidos el 22% fueron abandonados, y se evaluó el impacto de tres variables independientes en el abandono de los nidos. A saber: el proceso de construcción de la barrera de exclusión, las características del diseño de áesta y su localización geográfica. El proceso de la construcción de la barrera no estuvo relacionado al abandono de los nidos. Las características del diseño tampoco resultaron significativas. No obstante, las probabilidad de abandono resultaron significativamente mayor para barreras de exclusión con cubierta y aquellas que no contenían postes para verjas. Las barreras construídas en lugares mas al norte tuvieron niveles de abandono significativamente mayores. Se recomiendan diseños particulares para la construcción de barreras contra depredadores.

The Atlantic coast population of Piping Plovers (*Charadrius melodus*) was listed as threatened by the U.S. Fish and Wildlife Service under the Endangered Species Act in 1986. The causes of its decline have been attributed to loss or alteration of habitat (Haig and Oring 1985), human disturbance (Sidle 1985, Strauss 1990), and predation (Deblinger et al.

1992, MacIvor 1990, Rimmer and Deblinger 1990, Strauss 1990). Approximately 985 adult pairs nested in 1991 on a variety of beach habitats from North Carolina to Newfoundland (A. Hecht, unpubl. rep. U.S. Fish and Wildl. Serv., Newton Corner, Massachusetts, 1991).

Research and management efforts at Piping Plover breeding sites since 1986 have attempted to evaluate and alleviate limiting factors. Single-strand symbolic fences, total and partial beach closures, and educational programs have reduced human disturbance while aiding in the recovery of the species (Melvin et al. 1991). Wire-mesh exclosures of different sizes and shapes have been used to protect Piping Plover eggs from a variety of avian and mammalian predators (Melvin et al. 1992, Rimmer and Deblinger 1990).

The effectiveness of different exclosure designs for protecting Piping Plover nests from predators was reviewed by Deblinger et al. (1992); however, the impact of predator exclosures on nest abandonment has not been systematically evaluated. In general, Piping Plover nest abandonment is poorly understood and has received little attention in the literature. The few existing studies show divergent findings. Cairns (1977) and Ailes (1988) suggested annual abandonment rates as high as 11%, whereas MacIvor (1990) reported abandonment rates <1%. This paper examines the relationship of different predator exclosures on Piping Plover nest abandonment along the Atlantic coast during the 1990 breeding season. Characteristics of the exclosure construction process, the exclosure design and the geographic location of the site are evaluated.

METHODS

Data for this paper were ultimately obtained from state or provincial agencies responsible for endangered wildlife protection. In many cases, nonprofit organizations interested in Piping Plover conservation conducted the fieldwork. Each cooperator was asked to describe the exclosure construction process (e.g., construction time, time of day, number of people involved, number of visits required to complete construction and time elapsed before re-incubation), the design characteristics (e.g., size, shape, construction materials) of the exclosure used to protect Piping Plover nests, and to evaluate the effectiveness of the exclosure (e.g., hatch or fail, cause of failure).

Information was obtained on 211 exclosures in eight states and three Canadian provinces. Nests were discovered between 23 April and 12 July (median = 27 May). The exclosures were erected soon after nest discovery (1–8 d, median 4.2 d). Nests hatched between 21 May and 3 August (median = 6 June). Nests contained 1–4 eggs when they were first located (mean = 2.74, SE = 0.079). Exclosures were usually erected around nests with full clutches of four eggs (67%); some incomplete clutches also were exclosed (one egg [2%], two eggs [8%], three eggs [23%]). Of the 211 nests sampled, 64% were first nesting attempts when exclosed, whereas 25% were renests and 12% were unknown.

Exclosure Construction Process

The length of time needed to construct an exclosure depended on exclosure size and number of people. Construction time varied from 5 to 90 min (median = 16–20 min). Between one and six people (median = 3) were used to build an exclosure. Most exclosures were constructed in the morning (76%) during one (65%) or two (34%) sessions.

Exclosure Design Characteristics

A variety of styles and shapes of predator exclosures were used, but all consisted of some type of mesh fencing with its base buried in the substrate. Exclosures were constructed from welded wire (85%) or woven wire (8%) fencing with 5 × 5-cm (10%) or 5 × 10-cm (90%) mesh. Fence posts were metal or wood and varied in length from 1.2 to 2.5 m. At one site, a self-supporting exclosure completely lacking fence posts was used. Eighty-eight percent of the exclosures included a cover over the top to reduce avian predation.

Most exclosures were circular (79%) with diameters varying from 147 to 610 cm. Other styles included triangular (12%) and square (9%) exclosures. Width of straight-edged exclosures varied from 244 to 990 cm, and length varied from 244 to 990 cm. Other than one 990-cm/side square exclosure, the largest exclosures used were 990-cm/side equilateral triangles; the smallest were 147-cm diameter circles.

Variables

Dependent variables.—The dependent variable in this investigation was nest abandonment, defined as nests whose eggs were left permanently unattended by the adult pair prior to hatching for reasons other than overwash. Responses were coded as "Yes" or "No."

Independent variables.—Three types of independent variables were used to account for nest abandonment: exclosure construction process, exclosure design characteristics and geographic location. Construction process variables were recoded as dichotomous variables, and included number of people involved in exclosure construction (≤ 2 or >2), time of day (morning/late afternoon [i.e., $<1100/>1600$ hours] or mid-day [1100–1600]), time elapsed during construction (≤ 30 or >30 min), number of construction sessions (1 or >1), time elapsed after construction before re-incubation (<20 or ≥ 20 min).

Exclosure design variables included exclosure size ($<30{,}000$; 30,000–60,000; and $>60{,}000$ cm^2), shape (circle, triangle, or square), the presence or absence of a cover over the exclosure, posts used in construction (no/yes), post height (<122, 122, or >122 cm), the size of the mesh used in construction (5 × 5 or 5 × 10-cm), the height of the fence above the sand (<122 or ≥ 122 cm), and the depth of the fence into the substrate (≤ 10 or >10 cm). Selection of these indicators was based on prior Piping Plover predator exclosure research (Deblinger et al. 1992, Nol and Brooks 1982, Rimmer and Deblinger 1990).

As climatic conditions may influence nest abandonment, the effect of geographic location was examined. Location was treated as a three-level categorical variable: Canada (New Brunswick [two nests], Nova Scotia [16], and Prince Edward Island [17]), northern Atlantic United States (southern Maine [21], Massachusetts [49], Connecticut [25], New York [1], New Jersey [21], Rhode Island [4]), and mid-Atlantic United States (Virginia [55]).

Analysis

In the following analyses, our attention focuses on the odds of nest abandonment. For example, if n_1 is the number of exclosures where abandonment occurred, and $n - n_1$ are the exclosures with no nest abandonment (where n is the sample size), then the estimated odds of nest abandonment are:

$$\text{odds} = \frac{n_1}{n - n_1} = \frac{p}{1 - p},$$

where $p = n_1/n$ is the proportion of the sample where abandonment occurred.

We can calculate these odds for various combinations of the variables. The basic questions for analysis are: What are the odds of a nest abandonment, and do these odds vary significantly for exclosures with different construction/design characteristics in different geographical locations (i.e., different independent variables)? As odds data are not normally distributed, bi-variate log-linear models were used (Bishop et al. 1975; Goodman 1970, 1972). Sample sizes of nest abandonment were too small to allow use of multivarite logit models.

RESULTS AND DISCUSSION

Abandonment occurred at only 10% of the nests protected by exclosures. The odds of nest abandonment were 0.12–1 for the entire sample. Table 1 examines the relationships between each of the exclosure construction process variables and the odds of nest abandonment.

The time required to construct the exclosure was predicted to influence abandonment. A longer construction period implies a greater interval before the bird can return to incubate the eggs. This hypothesis was not supported (Table 1). When construction time exceeded 30 min, the odds of nest abandonment were 0.07–1; for construction times $\leq$30 min, the odds were 0.12–1. Applying the chi-squared test for marginal homogeneity indicated that these odds do not differ from the odds of nest abandonment for the entire sample ($\chi^2 = 0.51$, 1 df, $P = 0.476$). For this sample, then, knowing that the time required to erect the exclosure did not improve our ability to predict nest abandonment.

The number of people needed to construct the exclosure was hypothesized to be inversely related to abandonment. With more people, the exclosure can be erected more rapidly and thereby reduce the time the

TABLE 1. Estimated odds of piping plover nest abandonment along the Atlantic coast in 1990 (Bivariate exclosure construction models).

Independent variable	Nest abandonment: Yes %	Yes *n*	No %	No *n*	Estimated odds of nest abandonment	Chi-squared test for marginal homogeneity	*P*
Entire sample	10	22	90	189	0.12		
Exclosure construction							
Construction time						0.51	0.476
≤30 min	11	20	89	161	0.12		
>30 min	7	2	93	27	0.07		
Number of people						2.80	0.094
1–2	16	11	85	60	0.18		
3–6	8	11	92	129	0.09		
Number of visits						0.01	0.933
1 visit	10	14	90	122	0.11		
2–3 visits	11	8	89	67	0.12		
Time of day (hour)						1.12	0.291
<1100 or >1600	9	14	91	140	0.10		
1100–1600	14	8	86	48	0.16		
Re-incubation time						0.67	0.413
<20 min	10	17	90	148	0.11		
≥20 min	5	1	95	19	0.05		

bird is off the nest. Although the percentages for nest abandonment when only one or two people were involved in the process were double those when 3–6 people worked on the project (16% versus 8%), the *n*s were identical (11), and the chi-squared test was not significant ($\chi^2 = 2.80$, 1 df, $P = 0.094$). Similarly, there was no relationship between the number of visits needed to construct the exclosure and nest abandonment ($\chi^2 = 0.01$, 1 df, $P = 0.993$).

It was initially predicted that the time of day the exclosure was erected would influence nest abandonment. Exclosures constructed during the heat of the day (1100–1600 hours) were hypothesized to have higher abandonment rates than those constructed during the morning (<1100) or late afternoon (>1600). The prediction was not supported by this sample. The odds of nest abandonment were 0.16 during mid-day construction times and 0.11 for morning/late afternoon time periods. ($\chi^2 = 1.12$, 1 df, $P = 0.291$).

The last construction process variable was the amount of time before re-incubation. When this interval was <20 min, the odds of nest abandonment (0.11–1) were similar to that of the entire sample (0.12–1). When the re-incubation time period was ≥20 min, the odds were lower (0.05–1). The chi-squared was not significant ($\chi^2 = 0.67$, 1 df, $P = 0.413$).

TABLE 2. Estimated odds of piping plover nest abandonment along the Atlantic coast in 1990 (Bivariate exclosure characteristics models).

Independent variable	Nest abandonment: Yes %	Yes n	No %	No n	Estimated odds of nest abandonment	Chi-squared test for marginal homogeneity	P
Entire sample	10	22	90	189	0.12		
Exclosure characteristics							
Size						5.26	0.072
<30,000 cm²	26	6	74	17	0.35		
30,000–60,000 cm²	8	4	92	44	0.09		
>60,000 cm²	9	12	91	128	0.09		
Shape						1.06	0.590
Circle	11	19	89	147	0.13		
Triangle	8	2	92	24	0.08		
Square	5	1	95	18	0.06		
Cover						7.94	0.005
No	0	0	100	33	0.00		
Yes	12	22	88	156	0.14		
Posts						11.60	0.001
No	29	10	71	25	0.40		
Yes	7	12	93	164	0.07		
Post height						9.15	0.010
<122 cm	24	10	76	31	0.32		
122 cm	5	2	95	38	0.05		
>122 cm	8	10	92	120	0.08		
Mesh size						0.33	0.564
5 × 5 cm	14	3	86	18	0.17		
5 × 10 cm	10	19	90	170	0.11		
Fence height						0.58	0.445
<122 cm	15	4	85	23	0.17		
≥122 cm	10	18	90	166	0.11		
Fence depth						0.05	0.817
≤10 cm	10	6	90	56	0.11		
>10 cm	11	16	89	133	0.12		
Geographic location						13.57	0.001
Canada	29	10	71	25	0.40		
N. Atlantic U.S.	5	6	95	115	0.05		
Mid-Atlantic U.S.	11	6	89	49	0.12		

Overall, none of the construction process variables examined in Table 1 influenced nest abandonment. Table 2 evaluates exclosure design characteristics. The odds of nest abandonment when the exclosure was <30,000 cm² was 0.35–1, and 0.09–1 for larger exclosures (30,000–60,000 and

>60,000, respectively). Applying the chi-squared test for marginal homogeneity indicated that these odds differed from the odds of nest abandonment for the entire sample. The likelihood-ratio statistic for this 3 × 2 table was 5.26 ($P = 0.072$). Decomposing this table into two 2 × 2 tables indicates that the odds of nest abandonment were greater for smaller exclosures than medium sized exclosures ($\chi^2 = 3.78$, 1 df, $P = 0.05$). There were no differences between the medium sized and largest exclosures ($\chi^2 = 1.47$, 1 df, $P = 0.442$).

There was no relationship between nest abandonment and the shape of the exclosure ($\chi^2 = 1.06$, 2 df, $P = 0.590$). The odds of nest abandonment was 0.13–1 for circles, 0.08–1 for triangles, and 0.06–1 for square exclosures. Knowing the exclosure's shape does not improve our ability to predict nest abandonment.

Covering the exclosure, however, did influence the odds of nest abandonment ($\chi^2 = 7.94$, 1 df, $P = 0.005$). Of the 33 exclosures that did not have a cover, none were abandoned. Twelve percent of those with covers were abandoned (odds = 0.14–1).

The odds of nest abandonment (0.40–1) were significantly higher for exclosure designs that were self-supporting (no posts). The test for marginal homogeneity yielded a chi-squared of 11.60 ($P < 0.001$). Post height also was related to nest abandonment ($\chi^2 = 9.15$, 2 df, $P = 0.010$). The odds of nest abandonment was highest for posts that were <122 cm (0.32–1). Mesh size, fence height and fence depth were not related to nest abandonment.

Geographic location influenced nest abandonment. The odds of nest abandonment were highest in the Canadian provinces (0.40–1) where weather may have influenced the birds' behavior patterns. The overall likelihood-ratio statistic was 13.57 ($P < 0.001$). There was no statistical difference in abandonment rates between the northern and mid-Atlantic samples ($\chi^2 = 1.96$, 1 df, $P = 0.161$). Although we can envision why exclosures in Canada might flex under windy or stormy conditions and cause plovers to abandon their nest, it is less clear why exclosures in the other two geographic areas were abandoned.

Two possible explanations are offered. All 35 of the Canadian nests were self-supporting (no posts). The interaction of this design characteristic with the climatic conditions may have increased abandonment. The small size prohibited examination of this, as well as other possible interaction effects. It is also possible that predators who sense adult plovers within exclosures might attempt to enter exclosures causing alarm and eventually abandonment. Unfortunately, predator density and frequency of disturbance by predators are unknown.

SUMMARY AND RECOMMENDATIONS

Abandonment occurred at 10% of the nests protected with mesh fence exclosures along the Atlantic coast. This rate is comparable to the abandonment estimates of 11% reported by Cairns (1977) and Ailes (1988) for unexclosed nests. Within the limitations of this study, then, exclosures

did not lead to abnormal rates of nest abandonment. Further investigation, however, is necessary to verify this tentative conclusion.

Exclosure construction process was not related to nest abandonment. This result implies that if construction time, number of people and/or visits needed to erect the exclosure, and the time of day the structure is built, are kept to within the tolerance limits presented, they are not likely to affect Piping Plover recovery efforts adversely.

A disproportionate share of abandonment (10 of 22 nests) occurred in Canada, where climatic influences and exclosure design variables may have been responsible. The highest abandonment rate for any one beach (5/8 nests; 63%) occurred where a self-supported, small, circular exclosure lacking fence posts was used. Another exclosure design variable that significantly related to abandonment was the use of a cover. Of the 33 exclosures that did not have a cover, none were abandoned. Of the 22 nests that were abandoned, 16 (73%) had monofilament line covers and six (27%) used mist netting as a cover.

Exclosure cover designs are poorly understood and require further research to determine their effectiveness against avian predation. If avian predation is not suspected, exclosure covers should not be used. Although results from this survey suggest that abandonment rates were lowest for exclosures lacking covers and highest when monofilament line was used, the sample size of abandoned nests was small ($n = 22$). As little is known about Piping Plover abandonment under natural conditions, conclusions can not be drawn at this time and the use of exclosure covers should be carefully monitored.

Overall, wire mesh exclosures have been shown to reduce predation on Piping Plover nest and increase hatching success (Deblinger et al. 1992, Melvin et al. 1992, Rimmer and Deblinger 1990). Our data suggest that abandonment rates of nests protected with exclosures were similar to unexclosed nests from other studies (Ailes 1988, Cairns 1977). We recommend continued use of exclosures at breeding sites where predation limits Piping Plover hatching success. The size and shape of the exclosure should be sufficient to eliminate predator awareness of incubating adult plovers.

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