Wilson Bull., 112(1), 2000, pp. 14–20

ASSESSING THE EFFECTIVENESS OF PREDATOR EXCLOSURES FOR PLOVERS

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ABSTRACT.—We identified causes of nest failure and assessed the effectiveness of predator exclosures at Piping Plover (*Charadrius melodus*), Snowy Plover (*C. alexandrinus*), and Killdeer (*C. vociferus*) nests in southeastern Colorado during 1994–1995. Predation, nest abandonment, and weather were the primary causes of nest failure in all three species. For any of the three species we found no significant difference in the daily survival rate between nests that were protected by predator exclosures and nests that were unprotected. We reevaluated the experimental design and data analysis of previous predator exclosure studies and identified several confounding factors, including non-random assignment of exclosures, unbalanced sample sizes between protected and unprotected nests, data pooling across years, and inappropriate statistical analyses. We suggest ways to design (e.g., randomly allocate exclosures to nests and balance sample sizes between protected and unprotected nests) and analyze (e.g., use Mayfield method) future predator exclosure studies. *Received 25 May 1999, accepted 19 Oct. 1999.*

Conservation of endangered species requires a thorough knowledge of factors affecting their reproductive success and their survival during migration and winter. The Piping Plover (*Charadrius melodus*) and Snowy Plover (*C. alexandrinus*) are U.S. federally listed species throughout all or part of their ranges, respectively, in North America (U.S. Fish and Wildlife Service 1985, 1993, 1994b). Several factors may act to reduce Piping Plover and Snowy Plover reproductive success, including weather (Grover and Knopf 1982, Haig and Oring 1988, Sidle et al. 1992), nest abandonment (Cairns 1982, Grover and Knopf 1982, Warriner et al. 1986), and nest predation (Wilcox 1959, Grover and Knopf 1982, Page et al. 1983, Gaines and Ryan 1988, Haig and Oring 1988, Mayer and Ryan 1991, Paton 1995). Nest predation is considered a pervasive problem throughout the range of the Piping Plover (U.S. Fish and Wildlife Service 1994a, 1996) and has been documented as a primary threat to Snowy Plovers on their breeding grounds in California (Page et al. 1983) and Utah (Paton 1995).

One common technique used to reduce nest predation on shorebirds is to place predator exclosures around nests. Wire mesh predator exclosures have been used to protect Piping Plover nests on the Atlantic Coast, Great Lakes, and in the northern Great Plains (Rimmer and Deblinger 1990, Powell and Cuthbert 1992, Melvin et al. 1992) and Snowy Plover nests in California and Oregon (Page et al. 1995). Use of predator exclosures to reduce nest failure was a logical approach because nests could be protected from the primary nest predators including red foxes (*Vulpes vulpes*), striped skunks (*Mephitis mephitis*), raccoons (*Procyon lotor*), gulls (*Larus* spp.), and crows (*Corvus* spp.).

To determine whether predator exclosures are an effective management tool to increase productivity throughout the breeding range of Piping Plovers and Snowy Plovers, however, it is necessary first to identify which predators are causing nest failure at each breeding location. It is critical to use an appropriate experimental design and we extend previous work in this area by conducting field experiments to assess exclosure effectiveness. A valid experimental design can compensate for small sample sizes (e.g., balanced sample sizes provide greater power) that are typical of endangered species research and is essential to draw accurate conclusions regarding exclosure effectiveness.

We focused our study on the Piping Plover and Snowy Plover because of their declining status, and included the Killdeer (*C. vociferus*) as a reference species because it is common

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and its breeding habitat overlaps that of the other two species. All are ground nesting shorebirds that incubate 2–4 eggs for about 26–28 d (Haig 1992, Warriner et al. 1986, Powers 1978). We tested the null hypothesis that there were no differences in daily survival rates of protected and unprotected nests of each species, and *a priori* predicted that nests protected by exclosures would have a higher daily survival rate than unprotected nests. Our objectives were to (1) evaluate the effectiveness of predator exclosures for Piping Plovers, Snowy Plovers, and Killdeers in Colorado; (2) determine the causes of nest failure for these species; and (3) examine the experimental design and analysis of previous predator exclosure studies of plovers.

STUDY AREA AND METHODS

We placed predator exclosures over 9 Piping Plover, 27 Snowy Plover, and 16 Killdeer nests in southeastern Colorado from 20 May to 7 August 1994, and over 28 Snowy Plover nests from 19 April to 12 August 1995. Our study sites included shorelines of John Martin Reservoir (Bent County) and altered and unaltered playa lakes throughout Kiowa and Prowers counties. All locations were characterized by open sandy beaches or alkaline flats. Water levels in all water bodies varied markedly between years because of intense spring rains and above normal mountain snow pack in 1995.

Nest searching, marking, and monitoring.—We located nests by surveying shorelines of playa lakes from a small boat or by walking along the shoreline and scanning for adults with a spotting scope. We marked nest sites with small wooden garden stakes protruding 5–8 cm above ground and placed at least 10 m from the nest. We referenced nest site markers with a compass bearing and distance to an inconspicuous object at least 50 m from the nest site. We visited nests every 3–4 d and recorded the number of eggs and the presence of any predator tracks from at least 10 m away to minimize the effect of our presence at the nest. During 1995, we floated eggs twice during incubation to predict hatching date (Hill 1985, Alberico 1995).

Predator exclosures.—Upon finding the first nest of each species at each study site, we randomly decided whether to apply a predator exclosure by flipping a coin. Thereafter, we alternated between applying the treatment (exclosure) or leaving the nest as a control (no exclosure) at subsequent nests. This procedure balanced the sample size between control and treatment nests as much as possible.

We designed exclosures to exclude large avian predators and medium to large mammalian predators. Exclosures were not designed to prevent entry of small mammalian or reptilian predators because this would have prohibited access to the nest by the incubating bird. We based exclosure construction on designs developed previously for shorebirds (Nol and Brooks 1982, Rimmer and Deblinger 1990, Deblinger et al. 1992, Melvin et al. 1992, Estelle et al. 1996) but smaller than those recommended for Piping Plovers on the Atlantic Coast. We constructed cylindrical exclosures 61 cm high and 112 cm diameter, from 16 gauge, 5 × 5 cm wire mesh for Piping Plovers and Snowy Plovers, and 14 gauge, 5 × 10 cm wire mesh for Killdeers. We covered the top of the exclosures with the same wire mesh materials used for each species. We wove four pieces of steel rebar (1.3 × 91 cm) through the sides of each exclosure to secure it to the ground, buried the bottom 10 cm of the exclosure in the ground, and secured it with four 15–20 cm tent stakes. We installed exclosures within 1 day of locating a nest and measured the installation time and the time it took a bird to return to the nest and resume incubation (return time).

Nest fate.—We classified a nest as successful when we observed at least one chick in or near a scrape or when we found an eggshell top or bottom indicative of a hatched egg (Mabee 1997). We classified a nest as failed when (1) a clutch of eggs disappeared too early in incubation to have hatched, (2) the nest area contained indications of predation (e.g., broken eggs and/or predator tracks at a nest), or (3) the clutch was abandoned. If we suspected a clutch was abandoned (i.e., no adult observed incubating the eggs or present in the area), we reoriented the eggs in the scrape. If egg orientation had not changed and there was not an adult present in the area on the subsequent nest check (i.e., 3–4 d later), we considered the clutch to have been abandoned. We classified a nest as having an unknown fate when we could not determine nest fate.

Nest failure.—We used a combination of techniques to identify potential nest predators. First, when a nest became inactive (either hatched or failed), we searched at least a 10 m radius around a nest for predator tracks or eggshells. We inspected eggshells with a 10× lens for sign of tooth or beak marks. We identified large mammalian predators and occasionally snakes by the presence of tracks at a nest site (Murie 1982, Brown and Morgan 1983, Halfpenny 1986). We identified avian predators by the characteristics of eaten eggshells (Rearden 1951, Anderson 1971) or presence of tracks and/or pellets at a nest site. When a clutch failed inside an exclosure, we inferred predation by rodents if eggshells were found at or near the nest or by snakes if no eggshells were found. We made these assumptions because the 5 × 5 cm mesh of exclosures precluded most other possible predators from reaching the nest. We classified the cause of nest failure as unknown predation when eggs were missing from an unprotected nest, were too early in incubation to have hatched, and there was no distinctive predator sign.

We placed a mammal tracking tube near each nest in 1995 to determine the presence of rodents occurring in nesting habitat. Tracking tubes consisted of PVC pipe 5 cm in diameter and 31 cm in length with a removable liner (Mabee 1998). We placed tracking tubes in comparable nesting habitat an average of 30

TABLE 1. Daily survival rates (DSR) of nests protected with predator exclosures and unprotected nests of Piping Plovers, Snowy Plovers, and Killdeers in southeastern Colorado, 1994–1995. Z values calculated following Johnson (1979).

Species	Protected nests DSR ± SE (n)	Unprotected nests DSR ± SE (n)	Z (P)
1994			
Piping Plover	0.976 ± 0.017 (5)	0.988 ± 0.012 (4)	−0.43 (>0.10)
Snowy Plover	0.984 ± 0.009 (13)	0.983 ± 0.008 (14)	0.05 (>0.10)
Killdeer	0.966 ± 0.017 (7)	0.994 ± 0.006 (9)	−1.24 (>0.10)
1995			
Snowy Plover	0.977 ± 0.009 (14)	0.973 ± 0.011 (14)	0.20 (>0.10)

m away from nests so as to not attract small mammals to the nests. We developed a reference collection of tracks from small mammals trapped with Sherman traps at each of the study locations.

We classified clutches as abandoned when the complete clutch was abandoned and the eggs were fertile. Clutches that lost eggs to predators or cattle trampling and subsequently deserted were not classified as abandoned because the cause of failure could have been events preceding the nest abandonment.

Statistical analysis.—We calculated a daily survival rate for protected and unprotected nests for each species using the Mayfield method (Mayfield 1961, 1975) because it correctly weights the importance of successful, failed, or unknown fate nests by basing the daily survival rate on the number of nest exposure days. We calculated standard errors and tested for differences in daily survival rates between protected and unprotected nests with a Z test (Johnson 1979) and $\alpha = 0.10$. We selected this α level *a priori* because we expected small sample sizes and wanted to reduce the risk of a type II error. We also calculated observed nest success (successful nests/total nests) to facilitate comparison between studies that protected individual nests with predator exclosures and those that did not.

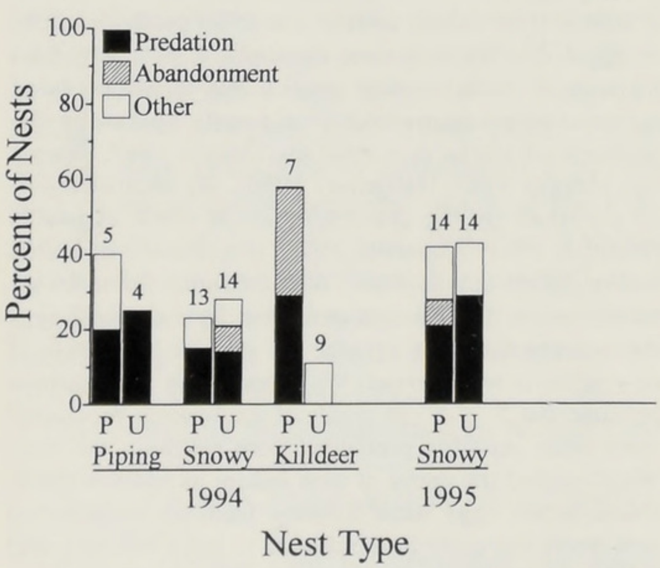

FIG. 1. Percent of protected (P) and unprotected (U) nests of Piping Plover (Piping), Snowy Plover (Snowy), and Killdeer that failed because of predation, abandonment, and other causes in southeastern Colorado, 1994–1995. Numbers above bars indicate sample size for each bar.

RESULTS

Effectiveness of predator exclosures.—Mean exclosure installation times (± SE) were similar among Piping Plover (13.0 min ± 1.3), Snowy Plover (12.2 ± 0.8), and Killdeer nests (9.5 ± 1.8) in 1994, and also for Snowy Plover nests (10.4 ± 0.7) in 1995. Average return times were similar for Piping Plovers in 1994 (6.0 ± 3.2) and Snowy Plovers in 1994 (6.1 ± 1.5) and 1995 (4.0 ± 1.1) but not for Killdeers in 1994 (25.0 ± 9.0). Because we collected return times opportunistically, we did not conduct statistical tests for differences among species.

We found no significant difference in the daily survival rate between protected and unprotected nests of Piping Plover (n = 5 protected, 4 unprotected), Snowy Plover (n = 13, 14), or Killdeer (n = 7, 9) in 1994 or Snowy Plover (n = 14, 14) in 1995 (P > 0.10 for all cases; Table 1).

Causes of nest failure.—No single predator or abiotic factor was responsible for most nest failure of the three species. Predation was the primary cause of nest failure during both years, whereas abandonment varied in importance by year (Fig. 1). Causes of nest failure classified as other included nest losses caused by cattle trampling, human disturbance or removal of eggs, beetles burrowing through eggs, sterile eggs, and partial clutch loss followed by abandonment. In 1994, protected nests were depredated by small predators, including snakes (n = 1), snake or Great Plains

TABLE 2. Observed nest success (number hatched/total nests) for nests protected with individual predator exclosures and unprotected nests of Piping Plovers, Snowy Plovers, and Killdeers in North America.

Species	Protected nests % (*n*)	Unprotected nests % (*n*)	Author
Piping Plover	92 (26)	25 (24)	Rimmer and Deblinger 1990
	90 (29)	17 (24)	Melvin et al. 1992
	60 (5)	75 (4)	This study 1994
	—[a]	0 (8)	This study 1995
	—	91 (4)	Wilcox 1959
	—	76 (51)	Cairns 1982
	—	36 (72)	Haig and Oring 1988
	—	35 (49)	MacIvor et al. 1990
Snowy Plover	69 (13)	57 (14)	This study 1994
	57 (14)	54 (13)	This study 1995
	—	53 (2123)	Page et al. 1995
Killdeer	33 (12)	29 (17)	Nol and Brooks 1982
	14 (7)	33 (9)	This study 1994
	—	24 (41)	This study 1995

[a] — No data.

skink (*Eumeces obsoletus*; $n = 1$), snakes or rodents ($n = 3$), and 2 clutches were sterile. In 1995, losses were caused by rodents ($n = 2$), snake or rodent ($n = 1$), sterile eggs ($n = 1$), and partial clutch loss by an unknown predator followed by abandonment ($n = 1$). Of all tracks identified at tracking stations placed in nesting habitat of all species in 1995, 99% were from deer mice (*Peromyscus maniculatus*), with the remaining tracks from northern grasshopper mice (*Onychomys leucogaster*) and an unidentified rodent. No large predators caused nest failure at protected nests in either year.

Unprotected nests in the exclosure experiment in 1994 failed because of Great Blue Heron (*Ardea herodias*) predation ($n = 1$), unknown predators ($n = 2$), a suspected burrowing beetle (*Geospinus* sp.) that burrowed through eggs ($n = 1$), and cattle trampling ($n = 1$); in 1995 unprotected nests failed because of unknown predators ($n = 4$), cattle trampling ($n = 1$), and partial clutch loss by cattle trampling followed by abandonment ($n = 1$).

DISCUSSION

Nest failure.—Although exclosures were exposed to predators of various sizes [e.g., coyotes (*Canis latrans*) to snakes], the protected nests appeared vulnerable only to reptilian or small mammalian predators. We observed bullsnakes (*Pituophis melanoleucus*) and coachwhips (*Masticophis flagellum*) commonly on the prairie and detected deer mice at all study sites. Deer mice were documented to eat or destroy eggs of nesting Spotted Sandpipers (*Actitis macularia*; Maxson and Oring 1978).

Unprotected nests were vulnerable to all predators, and this made it difficult to attribute predation to a specific species. We attributed 25 of 41 depredated nests to unidentified predators and no single identified predator species caused a majority of nest failure of the remaining nests. Early season plover nests were also vulnerable to tornadoes, hail storms, and flooding in 1995 that resulted in crushed eggs, inundated nests, and dead Killdeer chicks. Nest abandonment rates we observed fell within the range of values reported in other plover studies (Vaske et al. 1994). For comparative purposes, we examined the observed nest success of various plover studies. During 1994, the observed nest success for unprotected nests of Piping Plovers in our study area was higher than the average value from protected and unprotected nests found in other predator exclosure studies, whereas it was intermediate compared to several other non-exclosure studies (Table 2). During both years of this study, the average observed nest success for unprotected nests of Snowy Plovers was comparable to the average value obtained from non-exclosure studies throughout the breeding range (Table 2).

Predator exclosure study.—Our exclosures worked well structurally (no large avian or mammalian predators reached protected nests) and did not affect incubating behavior (all species entered and exited exclosures with ease). Ultimately, however, our exclosures did not increase the daily survival rates for Snowy Plover nests and the same appears to be true for Piping Plover and Killdeer nests. Although the small sample sizes may have diminished our ability to detect differences in the daily survival rate of Piping Plover and Killdeer nests in 1994, the results obtained from these species were consistent with those obtained from the larger sample of Snowy Plover nests in both years. Because Piping Plovers and Snowy Plovers are similar in several ways (behavior, nesting habitat, exposure to predators, causes of nest failure), we might expect exclosure effectiveness to be comparable for these species. Killdeers behaved differently, perhaps making them more susceptible to nest abandonment for protected nests and therefore require further study to assess the utility of exclosures.

The results of our predator exclosure study (especially for Snowy Plovers) stand in contrast to the results of studies that reported increased nest success associated with nest exclosures [Rimmer and Deblinger 1990 (χ^2 = 20.84, 1 df, $P < 0.001$), Melvin et al. 1992 (χ^2 = 26.64, 1 df, $P < 0.001$)]. We believe the main differences are due to different predator communities (i.e., most predation is from medium-sized birds and mammals on the Atlantic Coast in contrast to small animals in Colorado) and predation intensity (higher rates of predation on Atlantic Coast nests) and secondarily because of differences in experimental design. We examined the experimental design and analyses in other studies and determined that they assigned exclosures nonrandomly to nests, had unbalanced sample sizes of protected and unprotected nests both within and between years, pooled data across years, and used observed nest success (Rimmer and Deblinger 1990) as the metric to compare the effectiveness of exclosures. In contrast, Nol and Brooks (1982) and our study randomly allocated exclosures to nests, had nearly balanced sample sizes between protected and unprotected nests, did not pool data across years, and compared exclosure effectiveness with estimates based on the Mayfield method (Mayfield 1961, 1975).

Random assignment of exclosures to nests is essential to determine the degree of exclosure effectiveness because it controls for confounding factors such as investigator bias, stage of incubation, location, microhabitat, and time of season. In two studies, non-random treatment assignment resulted in artificially decreased rates of nest success for unprotected nests. This occurred because nests at which exclosures were not accepted, that failed during egg laying (Melvin et al. 1992), that were already destroyed when found, or that failed before exclosures could be applied, were classified as unprotected (control) nests (Rimmer and Deblinger 1990). Unbalanced treatment assignment leads to decreased power in statistical tests whereas data pooling across years can provide biased results.

The type of analysis used to determine the magnitude of a treatment effect is also important. For example, we used data from Nol and Brooks (1982) and found no significant difference in the observed rate of nest success between protected and unprotected nests using Fisher's exact test ($P = 0.737$), consistent with the authors' finding of no significant difference in overall rates of nest predation between protected and unprotected nests. However, this finding stands in contrast to the significant difference in daily survival rate between protected (0.963) and unprotected (0.951) nests that we calculated using the Mayfield method ($P < 0.001$). In another example, Rimmer and Deblinger (1990) and Melvin and coworkers (1992) compared the effectiveness of exclosures by using observed nest success data and the daily survival rate, respectively with χ^2 tests. Because daily survival rates are a proportion, they are not suitable for a χ^2 test (Zar 1998) but should be compared with a Z test (Johnson 1979). Observed nest success can overestimate actual nest success (Mayfield 1961, 1975) and hence may inflate exclosure effectiveness.

The primary objectives in the predator exclosure studies of Rimmer and Deblinger (1990) and Melvin and coworkers (1992) were to protect most of the Piping Plover nests, and the effectiveness of exclosures was analyzed retrospectively. This fundamental difference between their study objectives and ours created many of the differences that we have noted. We believe that exclosures increased nest success in both the Rimmer and Deblinger (1990) and Melvin and coworkers (1992) studies, although we may not be able to calculate the degree of exclosure effectiveness accurately.

To protect declining species such as Piping Plover and Snowy Plover on breeding grounds, we recommend that researchers (1) identify the causes of nest failure, (2) select an appropriate management tool (e.g., predator exclosures), (3) use a rigorous study design and analysis (e.g., Mayfield method) in order to test the effectiveness of exclosures, and (4) decide if predator exclosures are the most effective use of limited time and resources. We recommend that exclosures should not be used on Snowy Plovers in southeastern Colorado as long as small animal predators (e.g., reptiles and rodents) are the dominant causes of nest failure. Instead, we recommend increased protection of shorelines from disturbances caused by human activities and cattle grazing. Although it is likely that Piping Plovers will experience similar rates and causes of nest predation as Snowy Plovers in Colorado, additional study is needed for this species. Continued nest monitoring is needed for both species to ensure appropriate management recommendations in the future.

ACKNOWLEDGMENTS

We thank S. Earsom, J. Lynn, J. Bishop, and staff from the U.S. Fish and Wildlife Service (A. Archuleta, R. Brunotte, C. Ronish) for their valuable assistance in the field. We thank M. F. Carter (Colorado Bird Observatory) for encouragement throughout this study and C. Loeffler, J. Slater (Colorado Division of Wildlife), V. Harp and the U.S. Army Corps of Engineers rangers for logistic support. We thank the Van Horne–Wiens lab, J. A. Wiens, B. Van Horne, G. H. Rodda, P. G. Connors, E. C. Murphy, B. Sandercock, S. Melvin, and 2 anonymous reviewers for critiquing this manuscript. Financial support was provided by the Colorado Bird Observatory, Colorado Natural Areas Small Grants Program, Colorado Division of Wildlife, Frank M. Chapman Memorial Fund, U.S. Fish and Wildlife Service (Golden, Colorado), and Bureau of Land Management. This study was conducted under the U.S. Fish and Wildlife Service Federal Endangered and Threatened species permit number PRT-704930 and the Colorado Division of Wildlife scientific collection permit number 95-0119.

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