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Disturbance to wintering western snowy plovers

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Abstract

In order to better understand the nature of disturbances to wintering snowy plovers, I observed snowy plovers and activities that might disturb them at a beach near Devereux Slough in Santa Barbara, California, USA. Disturbance (activity that caused plovers to move or fly) to wintering populations of threatened western snowy plovers was 16 times higher at a public beach than at protected beaches. Wintering plovers reacted to disturbance at half the distance (~40 m) as has been reported for breeding snowy plovers (~80 m). Humans, dogs, crows and other birds were the main sources of disturbance on the public beach, and each snowy plover was disturbed, on average, once every 27 weekend min and once every 43 weekday min. Dogs off leash were a disproportionate source of disturbance. Plovers were more likely to fly from dogs, horses and crows than from humans and other shorebirds. Plovers were less abundant near trail heads. Over short time scales, plovers did not acclimate to or successfully find refuge from disturbance. Feeding rates declined with increased human activity. I used data from these observations to parameterize a model that predicted rates of disturbance given various management actions. The model found that prohibiting dogs and a 30 m buffer zone surrounding a 400 m stretch of beach provided the most protection for plovers for the least amount of impact to beach recreation. Published by Elsevier Science Ltd.

Keywords: Shorebirds; Pets; Recreation; Coastal; Conservation

1. Introduction

Shorebirds appear to be declining on large spatial scales (Howe et al., 1989, Brown et al., 2000a). Many use sandy beaches and are subject to disturbance from humans and pets that may reduce foraging efficiency and opportunities for rest (Brown et al., 2000b). For this reason, the US Shorebird Conservation Plan calls for increased research to determine how disturbance affects shorebird populations so that managed areas can be used for educational and recreational purposes while contributing to overall shorebird recovery goals (Brown et al., 2000b). Beach nesting species are arguably the most sensitive species to disturbance and several, particularly coastal plovers in the genus *Charadrius*, are endangered or threatened.

Western snowy plovers (*Charadrius alexandrinus nivosus*) are small shorebirds that use sand-spits, dune-backed beaches, unvegetated beach strands, open areas around estuaries, and beaches at river mouths for nesting and roosting (Wilson, 1980; Stenzel et al., 1981). The snowy plover breeding season on the West Coast of North America begins in early March and continues into September. Some winter where they nest, while others migrate (Page et al., 1995). Winter roosts may consist of 200–300 birds spread over 200 m along the upper beach; birds within the roost tend to aggregate. Individuals often sit in small depressions (on many beaches these are human footprints) or, when the wind is blowing, in the lee of beach debris.

The US Fish and Wildlife Service, lists western snowy plovers as a Threatened species under the Endangered Species Act. Habitat destruction, increased predator pressure, and increased beach recreation all correspond with the ongoing decline of snowy plover populations (Page et al., 1995). Beach recreation tends to be highest during the plover breeding season (March–September). If a parent is forced away from a nest, its eggs may die due to exposure or predation. Human activities detrimental to nesting include disruption of incubation and brooding and trampling of eggs and chicks. Causes of disturbance include pets (Stenzel et al., 1981; Warriner et al., 1986; Hatch, 1996), beach driving (Stenzel et al., 1981; Warriner et al., 1986; Page, 1988); horseback riding (Page, 1988); beach grooming (Stenzel et al., 1981), surf fishing (Fahy and Woodhouse, 1995), falcon flying, camping, jogging, clam digging, livestock grazing,

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sunbathing, picnicking, hang gliding, kite flying and model airplane flying (US Fish and Wildlife Service, 1995). Due to these impacts, snowy plovers have stopped breeding at 52 of the 80 former western US coastal nesting locations (Page and Stenzel, 1981).

Few human activities are lethal to roosting plovers and impacts are best understood in terms of how reduced opportunities to forage or rest could have cumulative impacts on reproduction and survivorship. In particular, short flights are energetically costly for small birds (Nudds and Bryant, 2000). Although energetic impacts are difficult to quantify, they can be indirectly inferred by quantifying disturbance rates because shorebirds unsuccessful in gaining necessary fat reserves apparently have very low survival rates (Brown et al., 2000b). An additional impact is the possibility that plovers will abandon a wintering site if disturbance is too intense. For example, at Goleta Beach in Santa Barbara County (CA), snowy plovers stopped breeding (but continued to winter) concurrent with the opening of beach access to humans. After three decades of increasing recreation, they permanently abandoned this site for wintering (M. Holmgren pers. comm.).

Because information suitable for managing wintering birds is relatively unavailable to managers, I investigated recreational activity and the responses of wintering western snowy plovers to understand how management actions might reduce disturbance to plovers during the non-breeding period. Based on similar studies done with other species and with breeding snowy plovers, I predicted that the effect of human activity on plovers would depend on the type of activity and decrease with increasing distance from plovers. I also predicted that rates of disturbance would be lower at areas where wintering plovers currently breed than at an area that they have abandoned for breeding. A unique aspect of the study was the use of disturbance rates to build a model that compared the efficacy of hypothetical management options such as removing dogs as a source of disturbance or closing sections of the plover roost to foot traffic.

2. Methods

2.1. Study sites

The primary study site was the public beach near Devereux Slough (32°25′00″ N, 119°52′30″ W). Devereux Slough is on the University of California Coal Oil Point Reserve on the Santa Barbara County mainland (California, USA). Snowy plovers no longer breed at Devereux Slough, but wintering snowy plovers roost among cobble, drift and depressions on a sandy delta formed by the slough mouth. At this site, snowy plovers are the most abundant bird species (Lafferty, 2001). They forage on invertebrates along the tidal margin and decomposing drift kelp. The beach has a rich high-intertidal invertebrate community, presumably due to the large amount of drift algae deposited on the beach from off-shore kelp forests (Dugan et al., 2000). Page and Shuford (2000) consider this site to be important snowy plover and shorebird habitat, and the US Fish and Wildlife Service designated 2.85 km of shoreline as Snowy Plover Critical Habitat in 1999 (such designation does not provide for active management). In addition to Devereux, we visited three sites (Santa Rosa Island, San Nicolas Island and Point Mugu Naval Base) to obtain an indication of the rates of disturbance to wintering plovers on beaches where they still breed. Human use of these beaches is very low because there is little to no public access.

2.2. Focal observations

With the help of an assistant, I observed the plover roost from a stationary position that was close enough to easily view plovers through binoculars, yet far enough that the plovers appeared to behave as if the observer was not present. Each potential disturbance agent that either came within 50 m of the roost, walked between the roost and the ocean or flew over the roost (e.g. aircraft) was noted whether it disturbed plovers or not. We estimated the shortest distance between the activity and plovers to within 5 m and recorded disturbances as causing plovers either to move or fly. Observation periods lasted for a minimum of 30 min and occurred between the hours of 10:00 a.m. and 2:00 p.m. We chose this time period because it was late enough that beach users were present but early enough that wind rarely interfered with sampling. Every 30 min, we counted plovers and noted the number that were roosting or actively foraging. We also noted weather and tide conditions at the start of the survey and collected beach profile data (width of wet sand, dry sand and moist sand). Sampling dates alternated between weekdays and weekends. We did not watch plovers on holidays.

On 7 and 8 April 2000 (one weekend day and one weekday), we conducted dawn to dusk observations of 16 non-breeding male birds at Devereux so that I could extrapolate mid-day disturbance rates into daily disturbance rates and determine how disturbance and plover behavior changed over the course of the day.

Including the dusk to dawn surveys, we observed the Devereux plover roost for 34 h, 18.5 h of which were between 10:00 a.m. and 2:00 p.m. (mid-day). We conducted 8.5 h of weekday mid-day observations, for 464 plover observation h (a plover observation hour is the equivalent of watching one plover for 1 h or 2 plovers for 30 min). Ten hours of mid-day observation were made on weekends, for a total of 500 plover observation

h. We analyzed data collected before 10:00 a.m. and after 2:00 p.m. separately from the mid-day observations (as specified in Section 3). We used the same focal observation techniques at Santa Rosa Island (four ~4 h observations south of Skunk Point, September 15–19, 1999), Point Mugu Naval Base (two 3 h observations at Nike Zeus, October 8 and 14, 1999) and San Nicolas Island (two 4 h observations at Coast Guard and Tender Beaches, February 3, 2000).

2.3. Beach surveys

In addition to the focal observations, we conducted 48 weekly shoreline surveys from January 1999 to January 2000 along the beach between the hours of 10:00 a.m. and 2:00 p.m. (see Lafferty, 2001). The survey transect covered the 2.8 km long Critical Habitat and helped map the location of the plover roost relative to beach features such as trailheads. Along the transect, we counted the number of plovers, as well as other animals and humans using the beach, moving rapidly enough so that the chance of double counting was low. We also recorded disturbances that clearly caused birds to fly or move. Disturbance agents were classified according to type and behavior. Survey dates alternated between weekends and weekdays. These data provided additional information on the types of activities that disturbed plovers.

2.4. Data analysis

I conducted statistical tests with the software package Systat 5.2.1 (Wilkinson, 1989). To evaluate disturbance rates, I used the Poisson distribution's estimate of the standard deviation with a sample size consisting of the number of plover observation hours to obtain confidence intervals of the number of disturbances per plover per hour. I evaluated the percentage of dogs vs. percentage of humans that disturbed plovers and the percentage of walkers vs. percentage of joggers that disturbed plovers with a Chi-Square test. I ran logistic regressions to compare how the probability of disturbance decreased with distance for dogs and humans. I calculated Pearson's correlation coefficients to test for associations between selected combinations of the following variables: average distance between people and the plover roost, tidal height, beach width, average distance at which plovers were disturbed, prior human activity, prior rates of disturbance and plover feeding activity (see Section 3 for combinations tested). Because I could not transform the data to meet the assumptions of ANOVA, I used a Kruskal–Wallis test to compare the means of feeding activity in the afternoon and morning among the disturbed and undisturbed beaches and to compare plover density (at Devereux) at roost areas adjacent to trail heads vs. areas not adjacent to trail heads.

2.5. Management model

To investigate the effect of different management options (closed areas of various sizes, pets vs. no pets), I constructed a deterministic mathematical model to investigate how disturbances to plovers might change if dogs did not disturb them and/or if buffer zones of various distances were maintained around wintering plovers (e.g. using signs and physical barriers). The metric I used for comparison was the number of flights caused by a disturbance, per bird, per hour, or $(f/b)/h$. This was the product of three proportions derived from the data: (1) the number of birds that flew divided by the number of disturbed birds, or f/d, (2) the number of disturbances per bird, per disturbance event, or $(d/b)/e$ and (3) the number of disturbance events per hour, or e/h.

A premise of the model was that disturbance should decline with increasing distance between plovers and the source of disturbance. I used the logistic regressions mentioned in 2.4 to determine the association between the distance of an activity and the probability of a disturbance, p, according to the extinction function $p=1/(1+\exp(-(1-C^*i)))$ where C is a constant that determines how fast the impact of an activity falls off with distance and i is the distance, in m, between the plover roost and a particular activity.

Multiplying p_i across the observed distribution of activity at different distances i from the roost yielded the association $e/h=\sum p_i N_i$ where N was the hourly rate of activity at distance i and i was summed from 0 to infinity. I simulated 10, 20 and 30 m buffer zones by moving all activity observed near the roost to the 10, 20 and 30 m distance bins (respectively) prior to summing across distances and calculating $f/b/h$. I simulated the effect of removing dogs as a source of disturbance by calculating $f/b/h$ for dogs and people separately and comparing the difference between people only and dogs and people.

To determine the relationship between the lateral length of a beach closure and the frequency that a closed area would contain all plovers, I first obtained east and west coordinates for the outer boundaries of the plover roost on each beach survey. I then used a simple iterative optimization model to determine the shortest distance along the shore that would contain a particular proportion of the roosts observed.

3. Results

3.1. Focal observations

At Devereux, we watched an average of 64 plovers per observation date ($n=38$, S.D.$=49$), yielding 1032 plover observation h. We observed 79 disturbances of the plover roost by people, pet dogs, equestrians, crows and other birds. On weekdays, 12.7 people ($n=17$, S.D.$=9.9$) and 1.4 dogs ($n=17$, S.D.$=1.8$) entered the Devereux site every 30 min during the mid-day observations. Of these, 12% ($n=241$) of the humans and 23% of the dogs ($n=26$) disturbed plovers at a rate of 20% of the roost per disturbing person and 26% of the roost per disturbing dog. Considering all disturbances, each plover was disturbed an average of 1.4 times per hour (Poisson S.D.$=1.2$, 95% confidence intervals from 1.29–1.51) or once every 43 min. Twenty-seven percent of the disturbed plovers flew ($n=650$).

On weekends, 20 people ($n=20$, S.D.$=12.3$) and 1.4 dogs ($n=20$, S.D.$=2.2$) entered the Devereux site every 30 min during the mid-day observations. Twelve percent ($n=401$) of the humans and 28% of the dogs ($n=29$) disturbed plovers at a rate of 20% of the roost per disturbing person and 73% of the roost per disturbing dog. Considering all disturbances, each plover was disturbed an average of 2.2 times per hour (Poisson S.D.$=1.5$, 95% confidence intervals from 2.07–2.33), or once every 27 min. Seventeen percent of the disturbed plovers flew ($n=1089$).

On average, 0.4 ($n=17$, S.D.$=2.1$) horses entered the site every 30 min during the mid-day observations. Sixty percent ($n=15$) of the horses disturbed plovers at a rate of 34% of the roost per disturbing horse. We did not record the rate at which birds (other than plovers) came near the roost (shorebird activity was high and rarely disturbed plovers). Seven crows disturbed plovers at a rate of 29% of the roost per disturbing crow. Other birds (particularly groups of black-bellied plovers, *Pluvialis squataroia*, and sanderlings, *Calidris alba*) were abundant near the roost and sometimes disturbed plovers as they walked or flew near the roost. Birds other than crows disturbed 41 plovers (or 2% of the total disturbances).

Although we did not see vehicles, their tracks appeared in the plover roost area every month or two. One airplane flying below 500 feet (the legal minimum altitude) caused the entire roost of 80 plovers to move but 12 other aircraft flying directly over the roost did not disturb plovers, presumably due to their higher altitude.

A higher proportion of dogs than humans disturbed plovers (2×2 Chi-Square$=10.3$, $P=0.001$). Only 21% of dogs were leashed even though posted regulations required leashing. Leashed and unleashed dogs disturbed plovers but there was an insufficient sample size of leashed dogs to test the hypothesis that leashing reduced the likelihood of disturbing plovers. For humans, a smaller proportion of joggers (6%, $n=161$) disturbed plovers than did walkers (19%, $n=520$, 2×2 Chi-Square$=16$, $P<0.0001$), this unexpected result was apparent even after controlling for distances between humans and plovers.

To estimate the weekly rate of disturbance for an individual plover, I calculated the ratio between the hourly rate of disturbance in midday (2.2 disturbances/plover/hour on weekends and 1.4 disturbances/plover/hour on weekdays) and the daily amount of disturbance from the weekend and weekday dusk to dawn surveys. The daily amount was 8.8×2.2 for a weekend day and 10.9×1.4 for weekdays. The estimated weekly disturbance was, therefore, 115 disturbances per plover per week. Given the mean abundance of plovers at the site throughout the entire year (60 birds, personal observation), there were an estimated 3100 "plover weeks" and 356,000 disturbances to plovers each year.

Rates of disturbance at Devereux were high compared with beaches where plovers presently breed. On Santa Rosa Island, plovers were not disturbed during 16 h of observation, representing 329.5 plover observation h. At Point Mugu Naval Base, an osprey, *Pandion haliaetus*, disturbed seven plovers during 88 plover observation h and on San Nicolas Island, nine disturbance events (by other shorebirds, a kestrel, *Falco sparverius*, and an elephant seal, *Mirounga augustirostris*), during 264 plover observation h, disturbed 55 plovers. In total, on protected beaches, each wintering bird was disturbed 0.023 times per h (Poisson S.D.$=0.15$, 95% confidence intervals from 0.011–0.034). This was the equivalent of once every 11 mid-day h (sites pooled) or once every 10.4 mid-day h (sites averaged), compared with once every 38 min at Devereux (a 16-fold difference).

The distance between human activity and the roost peaked at about 30 m and relatively few people or dogs beyond this distance disturbed plovers (Fig. 1a and b). The number of individual people or pets in a group did not significantly alter the probability of disturbance (Logistic regression, Chi-Square$=1.9$, d.f.$=8$, $P<0.98$). Both logistic regressions (Fig. 2) indicated that the probability of a disturbance decreased with the distance from activity (Chi-Square$=48.3$, d.f.$=1$, $P<0.0001$) and that, at any particular distance, dogs had a higher probability of disturbing plovers than did humans (Chi-Square$=5.3$, d.f.$=1$, $P=0.02$).

The distance between people and the plover roost increased with the width of the beach ($R=0.47$, $n=17$, $P<0.05$), presumably because a narrow beach increased the potential overlap between beach users and snowy plovers. Much of the variation in beach width was a function of tidal height ($R=-0.48$, $n=17$, $P<0.05$) but it was also affected by seasonal variation in the distribution of sand; in the winter and early spring, the beach was narrower due to the scouring action of storms.

3.2. Dusk to dawn surveys

Human activity was lowest in the mornings and increased throughout the day. An analysis of the dawn to dusk surveys found no indication that plover sensi-

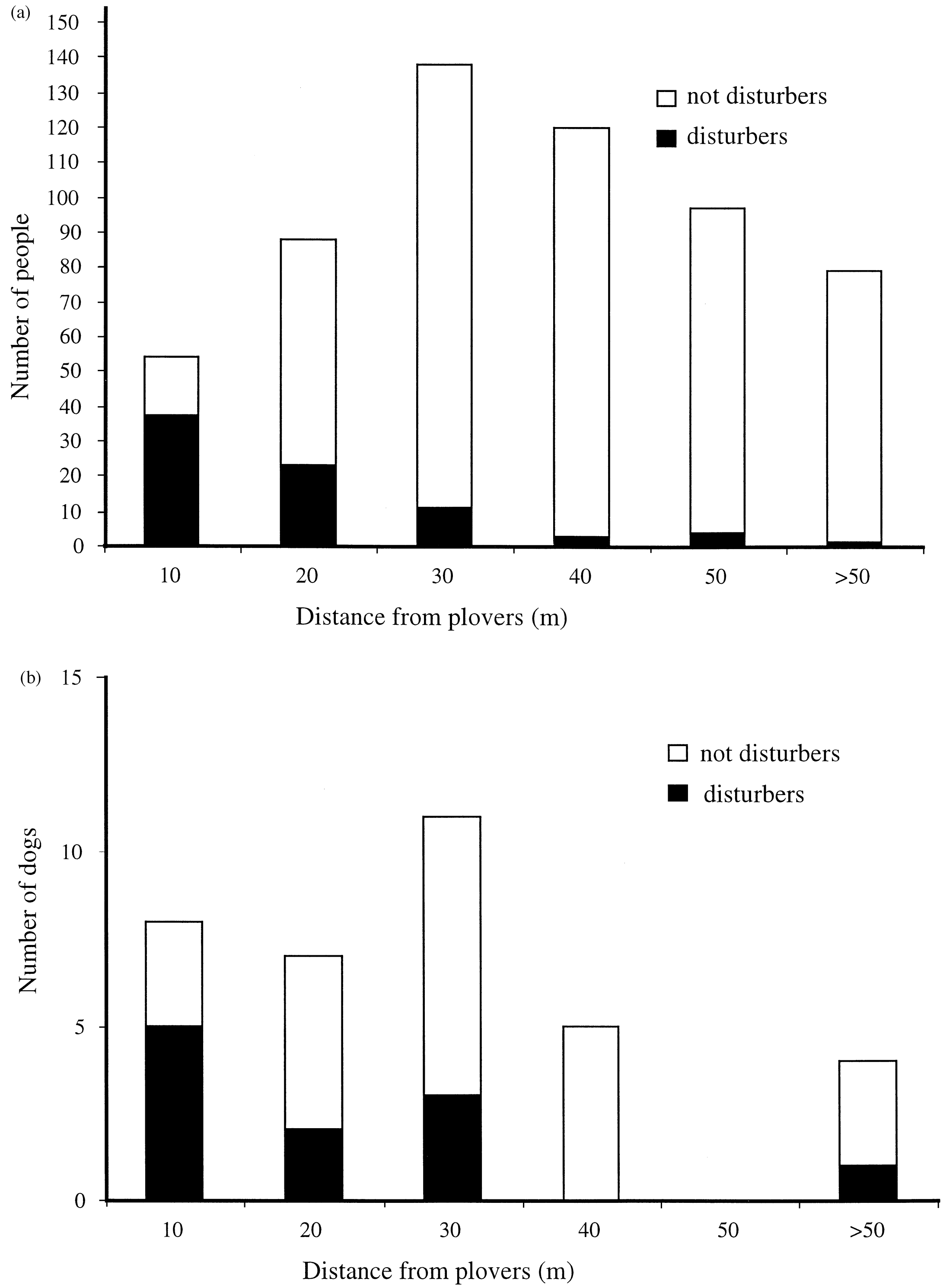

Fig. 1. (a) The nearest distance people came to the roost. The distance axis represents the minimum distance that a person came to a snowy plover. The solid fill represents those people that disturbed plovers (in this case, the distance represents how close the person was at the time of disturbance). (b) The nearest distance dogs came to the roost (see Fig. 4a).

tivity (measured as the average distance at which plovers were disturbed) changed with respect to the previous amount (summed over 2 h) of human activity ($R=0.02$, $n=34$, $P>0.05$) or human disturbance ($R=0.11$, $n=34$, $P>0.05$). There was no association between the average distance between plovers and people and the previous two hours of human/pet activity ($R=0.19$, $n=49$, $P>0.05$) or disturbance events

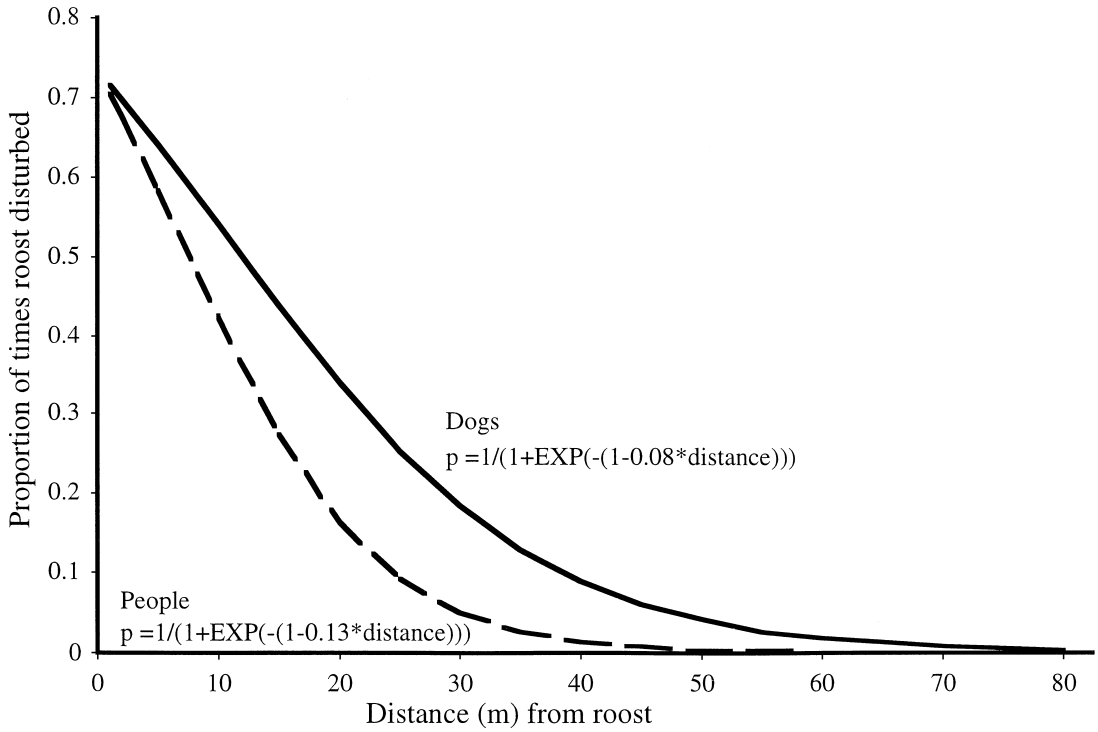

Fig. 2. The association between distance to the roost for people (dashed line) or dogs (solid line) and the probability of a disturbance. This estimation was based on a logistic regression applied to the data shown in Fig. 1a and b.

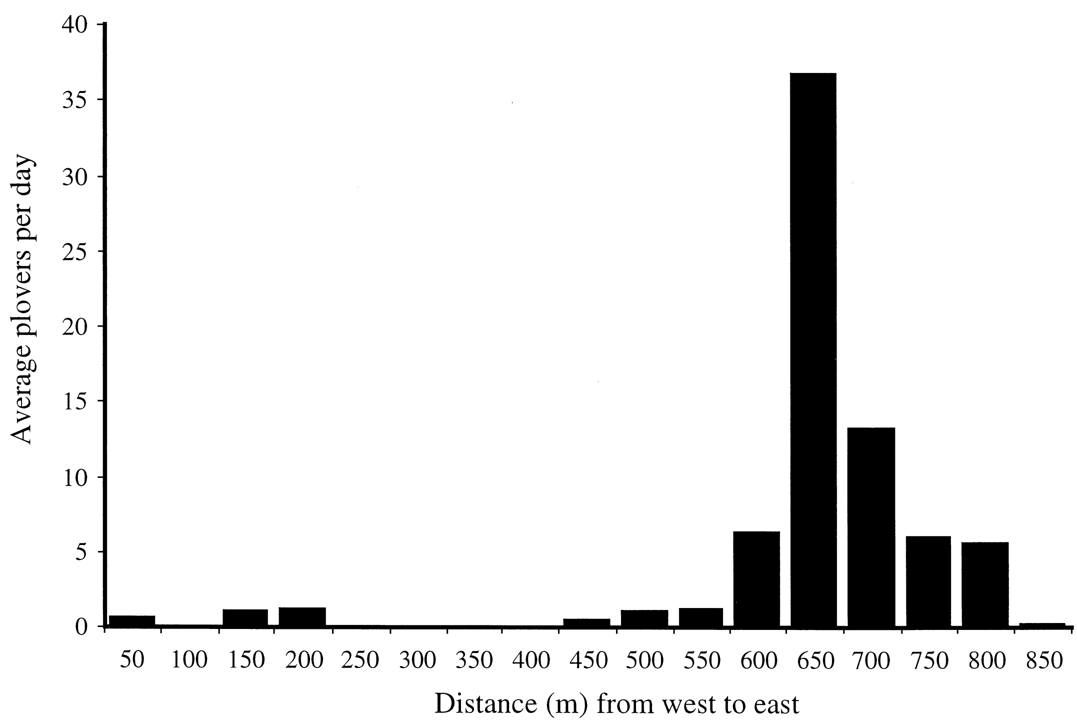

Fig. 3. The west–east distribution of snowy plovers. The location of the roost varied from day to day and often included more than one distance bin. Devereux Slough mouth was located between the 550 and 700 m marks.

($R=0.03$, $n=49$, $P>0.05$), suggesting that disturbed plovers, though they moved away from each disturber, were not successful at finding areas with low levels of human activity. A similar analysis across dates found negative but non-significant associations between the average distance at which humans disturbed plovers and

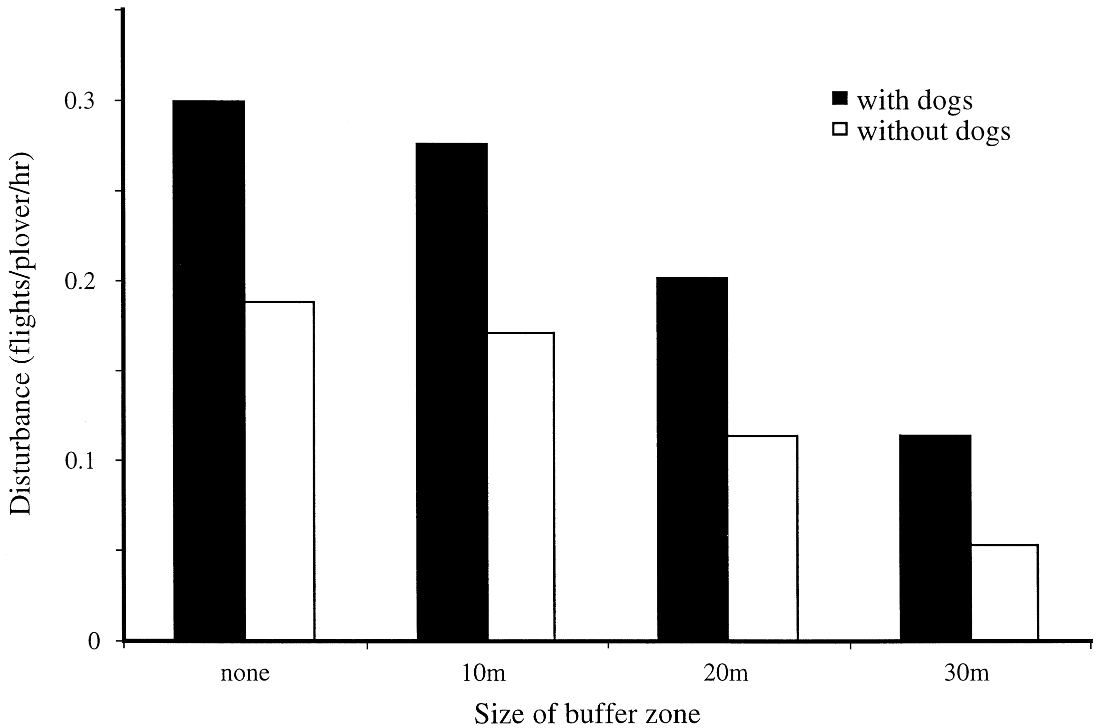

Fig. 4. The effect of removing dogs as disturbers and/or establishing a buffer zone around the plover roost of various distance. These predictions were based on data shown in Figs. 1–3.

the amount of human activity on the beach ($R=-0.41$, $n=16$, $P>0.05$) and the proportion of the roost that was disturbed on that date ($R=-0.20$, $n=16$, $P>0.05$).

During the dawn to dusk surveys, an average of 43% of the plovers fed in the morning until about 10:30 a.m. Later, most plovers (95%) roosted unless disturbed. Plover feeding activity declined with the abundance of beach users ($R=-0.42$, $n=53$, $P<0.01$) who were more abundant in the afternoon. Only after dark did we see plovers feeding again.

Data on the proportion of plovers feeding before and after 10:30 a.m. from the protected beaches allowed a preliminary investigation into the effect of disturbance on feeding activity. There was a significant effect of time of day (39 early vs. 9% late, Mann Whitney $U=2073$, $n=113$, d.f.$=1$, $P<0.001$), but not an overall effect of protected vs. public beach (24 vs. 24%, Mann Whitney $U=1451$, $n=113$, d.f.$=1$, $P=0.37$) on feeding. However, less late-day feeding occurred at Devereux relative to the protected beaches (5 vs. 13%, Mann Whitney $U=564$, $n=82$, d.f.$=1$, $P=0.002$).

3.3. Beach surveys

Snowy plovers roosted in one or two clusters along an 850 m stretch of dry sand near the mouth of Devereux Slough. Plover habitat utilization dropped off sharply to the east of the slough and more gradually to the west of the slough (Fig. 3). Roosting birds typically occurred in one or two dense aggregations and the mean lateral stretch of beach occupied by the plover roost was typically 37 m (mode and median) wide. The density of plovers was lower in areas at the heads of four beach access trails compared with other areas where plovers roosted (0.1 birds per 2500 m^2 vs. 4.6 birds per 2500 m^2, $n=19$ sites, Mann Whitney $U=11$, $P=0.045$).

3.4. Causes of intense disturbance

I combined data from the focal observations and the beach transects to assess 3994 disturbed plovers. Humans disturbed 2270, dogs 881, crows 531, horses 166, airplanes 80 and birds 66 plover. When only considering the 1333 plovers that flew, humans disturbed 628, crows 322, dogs 316, horses 66, and birds 1 plover(s). By dividing the numbers of plovers that flew by the total number of disturbed plovers, it was possible to determine that plovers flew relatively little in response to other birds (21%) and humans (28%), an intermediate amount in response to dogs (36%) and horses (40%) and most in response to crows (61%).

3.5. Management

Fig. 4 presents results from the management model which estimated intense (flight response) disturbances under different scenarios. Removing disturbance due to dogs dramatically reduced disturbance in all scenarios

Fig. 5. The association between the size of an optimally placed closed area and (1) the average number of plovers on the beach that would be contained within a 30 m buffer from human activity (solid line) and (2) the proportion of dates on which the plover roost would fall within a 30 m buffer from human activity (dashed line). The predictions were based on a model parameterized from the data represented in Fig. 3.

(e.g. simply removing dogs reduced disturbance from 0.3 to 0.18 flights per bird per h). The 5 m and 10 m buffer zones were relatively ineffective, while 20 m and 30 m buffer zones reduced disturbance to 67% and 38% of the total, respectively. Although not shown, the results from the model were directly proportional to the amount of human activity. In other words, doubling the frequency of people and/or dogs simply would have doubled the rate of disturbance for all categories.

Increasing the lateral length of beach that was hypothetically closed to human activity sharply increased the proportion of dates on which the plover roost was protected up until a distance of 400 m, at which over 90% of the roosts and 96% of the plovers gained protection (Fig. 5). Increasing the closed area beyond 400 m did not achieve as great a gain in protection per metre closed.

4. Discussion

4.1. Observations

The main result from this study was that snowy plovers were most frequently disturbed when approached closely by people and animals. There was clear evidence of a disproportionate effect of dogs on plovers and some evidence that plover feeding was affected by activity on the beach. Such a high rate of disturbance events (4.3 per h) may prevent snowy plovers from using Devereux to breed. Similarly, at Ocean Beach (San Francisco), there are 4.5 disturbance events per h to wintering snowy plovers and snowy plovers do not nest (Hatch, 1996). Plovers did not appear to significantly acclimate to high rates of disturbance at Devereux (in fact, most shorebirds at Devereux have increased sensitivity when disturbance is high (Lafferty, 2001).

Plovers flew readily in response to crows, perhaps because crows can prey on eggs and chicks. Crows also disturb other bird species using the beach (Lafferty, 2001). Crow abundance has steadily increased in Santa Barbara County over the last two decades (Lehman, 1994). Along the beach, their abundance increases with proximity to a nearby (<2 km) urban area (Lafferty, 2001), probably because crows thrive in urban settings (Ward and Low, 1997). Crows fed on litter left by beach users and used exotic trees planted near Devereux Slough to roost and nest.

Disturbance appeared to alter the spatial distribution of plovers at Devereux. Roosting plovers were less abundant near the heads of beach trails, suggesting that repeated foot traffic degraded these areas for plovers so that plovers avoided them. In contrast, within the main roost area at the mouth of Devereux Slough, plovers that moved in response to a disturbance were not able to find predictably isolated areas to roost, perhaps because, unlike at the heads of trails, foot traffic through the delta area was relatively random. Snowy plovers, because of their site fidelity and narrow habitat requirements, have few alternative roosting sites. Some shorebirds do leave disturbed areas (Burger, 1981, 1986). On Ventura County (CA, USA) sand beaches, for example, shorebird abundance declines with increased human use, presumably because disturbance causes birds to seek more isolated locations (McCrary and Pierson, 2000).

Birds that forage slowly or ineffectively may not build the requisite fat reserves needed for migration and reproduction (Puttick, 1979). Studies on the closely related piping plover, *Charadrius melodus*, indicate that reproductive success is lower in areas with high human disturbance because of reduced foraging efficiency and the depletion of fat reserves (Burger, 1986, 1991, 1994; Flemming et al., 1988). In areas where people are absent, piping plovers can spend 90% of their foraging time feeding compared with less than 50% in areas where people are common (Burger, 1994). Human activity also affects the foraging of wintering sanderlings (Burger and Gochfeld, 1991). The shift in foraging from afternoon to the early morning at Devereux, may have been a result of higher amounts of disturbance in the afternoon. However, the extent to which human activity or time of day actually affected feeding was unknown because prey availability, satiation and wind probably also affected snowy plover foraging patterns in this study and varied with the time of day. For example, taltrid amphipods (*Megalorchestia* spp.) were more abundant during the morning and late evening hours while kelp flies, *Coelopa vanduzeei*, appeared active all day. Had we observed plovers more in the early morning when they were feeding, we might have seen a more pronounced effect of disturbance on feeding rates. Disturbance might force shorebirds to feed at night (Burger, 1984; Burger and Gochfeld, 1991). Plovers have excellent night vision (Rojas et al., 1999) and fed on amphipods in near total darkness at Devereux, perhaps because disturbance limited opportunities to feed in the day.

In general, shorebirds at this site are very sensitive to dogs on the beach (Lafferty, 2001). Similarly, on the East Coast, piping plovers react at twice the distance and are displaced twice as far by dogs as they are by pedestrians (US Fish and Wildlife Service, 1996). Such sensitivity may derive from being chased by dogs or because birds instinctively view dogs as predators (Gabrielsen and Smith, 1995). Pet activity can reduce shorebird abundance (Burger, 1981; Klein, 1993) and those birds that remain must spend more energy on vigilance and escape at the expense of foraging and resting (Pfister et al., 1992; Burger, 1994).

The wintering plovers in this study were less than half as sensitive to disturbance as breeding plovers at Vandenberg Air Force Base (VAFB). At VAFB, 40% (vs. 12% at Devereux) of the people using the beach and 70% (vs. 31% at Devereux) of unleashed pets disturbed plovers (Fahy and Woodhouse, 1995). In addition, breeding plovers reacted at greater distances to a disturbance; it was only at >80 m (vs. 30–40 m at Devereux) that activity did not disturb plovers (Fahy and Woodhouse, 1995). Therefore, data from Devereux should not be applied to breeding snowy plovers.

4.2. Management

The disturbance data were useful for parameterizing models which indicated that active management (pet prohibition/closed areas) of a small fraction ($\sim$15%) of the Critical Habitat at Devereux could greatly reduce disturbance. Although beach closures have successfuly protected snowy plovers during the breeding season (Page 1990), closures to protect wintering birds are, to my knowledge, limited to Point Mugu Naval Base and the mouth of the Santa Ynez River. The hypothetical nature of the management model should be cast in light of the difficulty of obtaining compliance. For example, at nearby Vandenberg Air Force Base (VAFB), 30% of beach users entered posted closed areas where plovers breed and roost (Fahy and Woodhouse, 1995).

Voluntary compliance with posted pet regulations is also often low. The effect of leash laws on reducing disturbance to snowy plovers is a product of the effectiveness of a leash and the level of compliance. Although leashing makes it difficult for pets to chase birds and reduces the probability of disturbance and the number of birds per disturbance, leashed pets still disturb birds (Lafferty, 2001). For example, Fahy and Woodhouse (1995) observed that leashed pets were about half as likely to disturb snowy plovers as unleashed pets. With education and posting, but without enforcement, 10% of owners leashed their pets at Ocean Beach (Hatch, 1996), 7% of pets were on leash along the Critical Habitat at Devereux (Lafferty, 2001) and 21% of pets were on leash in the Devereux plover roost. At VAFB, posting and a moderate enforcement presence (15% of daylight hours) brought compliance with the leash law to 30%. Full-time enforcement at Ocean Beach brought compliance to near 100%, mostly because pet owners moved their activity to adjacent beaches lacking enforcement (Hatch, 1996).

Increasing coastal human populations throughout the world will continue to generate conflicts between coastal recreation and shorebird populations because both depend on a very narrow strip of habitat. For this reason, the Southern Pacific Coast Regional Shorebird Plan proposes limiting human disturbance to shorebirds (Page and Schuford, 2000). Although laws requiring the protection of listed species such as the snowy plover may influence the management of coastal habitats, Brown et al. (2000b) recommend that management strategies consider entire shorebird guilds rather than single species. It is therefore worth considering that wintering snowy plovers are less frequently disturbed than most other shorebirds because (1) snowy plovers are relatively hesitant to move or fly from a person or dog and (2) snowy plovers roost in the dry sand away from most foot traffic (Lafferty, 2001). Despite these differences, snowy plovers can act as an important umbrella species in the sense that restricting pets on beaches in order to protect snowy plovers will benefit the entire shorebird guild.

There are two ways that managing for snowy plovers could inadvertently increase disturbance to other shorebirds. Firstly, restricting pets only from core snowy plover roost areas might increase the density of pets immediately outside the managed area (Hatch, 1996). In the case of Devereux, shorebirds are very abundant at the rocky point just east of the plover roost and displacing pets to this area could inadvertently increase the effect of dogs on other shorebirds. Therefore, it may be useful to anticipate an edge effect of enforcement in terms of the distribution of other wildlife using adjacent habitats. Secondly, requiring people to walk along the wet sand to avoid snowy plovers concentrates activity into precisely the location where disturbances to most other bird species occur. This means that upper beach closures to protect plovers should be limited to core plover areas in a manner consistent with the management model developed here.

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