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EFFECTS OF A CHANGING ENVIRONMENT ON NESTING SNOWY PLOVERS AT OWENS LAKE, CALIFORNIA

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ABSTRACT: Fourteen lakewide surveys for breeding Snowy Plovers (*Charadrius alexandrinus*) have been conducted at Owens Lake over three decades. There was a steep decline from 499 adults on the first survey in 1978 to 195 on the second in 1988. Nine subsequent counts from 1990 to 2001 varied from 101 to 203 adults (mean 138, standard error 11). After the introduction in 2002 of water to large areas for dust control, numbers of adults increased annually to 658 in 2004. Shallow flooded areas now account for 85% of the adults. The distribution of nests has also changed since the addition of water. The area of most extensive shallow flooding accounted for 71% and 61% of the nests found in 2002 and 2003, respectively, compared with only 27% in the area in 2001 prior to flooding. The nesting season has also been extended by about a month since the plovers began nesting in flooded areas. At Owens Lake Snowy Plovers have benefited from the shallow flooding for dust control but are now more dependent on man-made habitat.

In western North America 10,000–20,000 Snowy Plovers nest at interior alkaline lakes, on Pacific beaches, and in man-made evaporation ponds (Page and Stenzel 1981, Herman et al. 1988, Page et al. 1991, Palacios et al. 1994, Page et al. 1995). After the U.S. Fish and Wildlife Service designated the Pacific coast population as threatened in 1993, breeding Snowy Plovers were monitored at many coastal sites (Powell et al. 2002, Ruhlen et al. 2003, Neuman et al. 2004) but at few interior ones (Shuford et al. 2004). One of the few inland sites of regular censuses is Owens Lake, where we have counted breeding plovers annually since 1994 and have located their nests from 1999 to 2003.

Fisher (1893) provided the earliest account of the Snowy Plover at Owens Lake during the breeding season, describing it as "common" in small flocks of 5 to 10 on alkaline flats bordering the lake near Keeler, 30 May to 4 June 1891. He believed the plovers were breeding there even though he found no eggs or young. Tom and Jo Heindel were the first to confirm

breeding at Owens Lake, noting 130 adult-sized plovers accompanied by downy young in July 1975 (McCaskie 1975). The first lakewide survey for breeding Snowy Plovers recorded 499 adults in 1978 (Page and Stenzel 1981). Follow-up surveys in 1988 and 1990 documented only 195 and 141 adults, respectively (Page et al. 1991, this paper).

Small populations of birds living in environments subject to human alterations are susceptible to the effects of habitat changes and hence should be monitored to ensure these changes do not jeopardize their viability. In particular, human alterations may affect the carrying capacity of the habitat, nesting behavior, or reproductive success, to the benefit or detriment of the species. The Owens lakebed has been subject to major alterations since 2001 resulting from a 1998 agreement between Los Angeles Department of Water and Power (LADWP) and the Great Basin Unified Air Pollution Control District (GBUAPCD) to control the dust that blows from the dry lakebed. Dust-control measures, intended to bring the region into compliance with federal air-quality standards, include shallow flooding of sizable portions of the lakebed. The first area to be flooded was inundated in winter 2001–02; three additional ones followed in winter 2002–03. This addition of water to large areas of formerly dry lakebed has substantially altered breeding habitat for Snowy Plovers at Owens Lake. Here we report the effects of shallow flooding on the total numbers, distribution, duration of breeding season, and nest placement of Snowy Plovers at Owens Lake.

STUDY AREA AND METHODS

Owens Lake is the remnant of a large prehistoric freshwater lake 1128 m above sea level at the western edge of the Great Basin desert in Inyo County, California. In the early 1900s, it covered about 280 km^2 but since the late 1920s it has been essentially dry, except for limited spring inflow, because of diversion of the Owens River and tributary streams by the city of Los Angeles. As the lake evaporated, dissolved minerals in the water crystallized into the alkali crust now covering most of the lakebed. The remaining wet areas are small isolated springs or seeps originating from underground water sources, the Owens River delta, and a brine pool in the center of the lake. The flow of these seeps onto the lakebed, or lack thereof, varies both annually and daily, particularly during the hot summer.

The region is typically hot and dry in summer and cold in winter and spring, with periods of high winds. From 1971 to 2000 maximum temperatures in the nearby town of Independence averaged 28° C in May, 33° C in June, 37° C in July, 36° C in August, and 13° C in both December and January (Western Regional Climate Center, http://www.wrcc.dri.edu/index.html). Average minimum temperatures ranged from 11° to 18° C from May to August and were lowest in December and January at –2° C. Average annual precipitation was 13.2 cm with monthly averages ranging from 0.3 to 0.5 cm during the spring and summer (Western Regional Climate Center, http://www.wrcc.dri.edu/index.html).

The most obvious anthropogenic effect on the habitat during the past three decades is the large release of water onto the lakebed. This occurred on the 1978 survey when water flowed on the lakebed from four creeks on

the west side (Henderson and Page 1979) and from 2002 to 2004 with the spraying of water piped underground from the Los Angeles Aqueduct to flood extensive areas to reduce wind-driven dust. By summer 2004, 40.8 km^2 of shallowly flooded habitat were included within zones 1 and 2 and phases 1 and 2 (Figure 1).

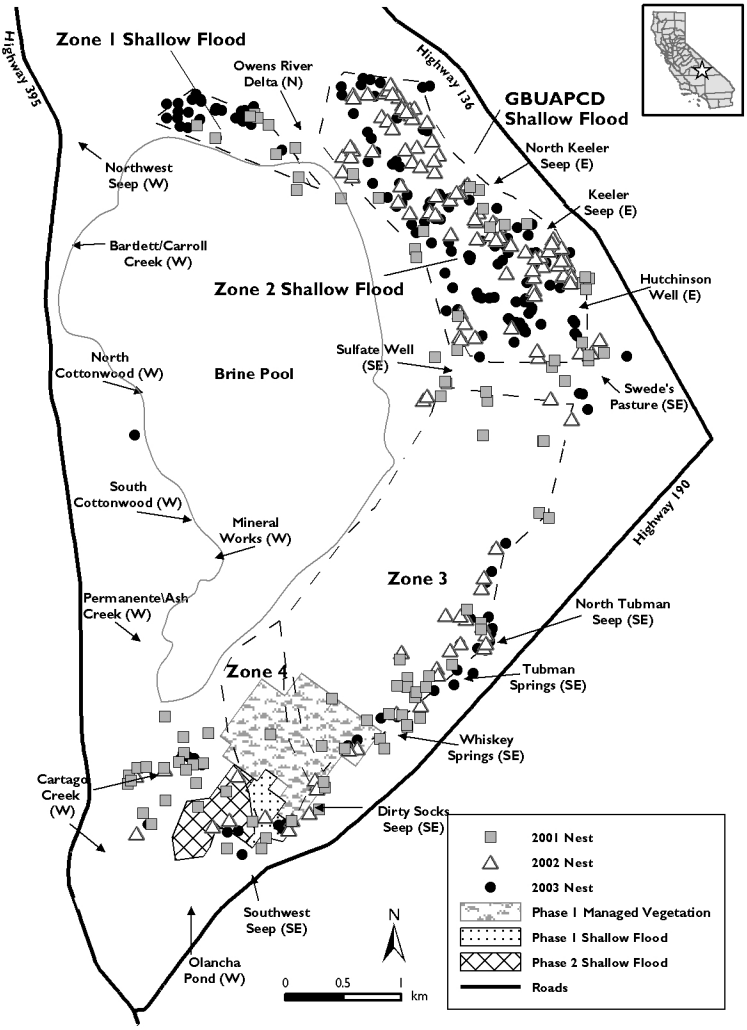

Figure 1. Survey locations and 2001–2003 distribution of Snowy Plover nests at Owens Lake. Regions of the lakebed are west (W), north (N), east (E), and south/southeast (SE).

The flooded areas consist of shallow ponds, mudflats, and dry alkali crust, surrounded and subdivided by roads and berms. In 2002, as a by-product of furrows dug with farm equipment to channel water, the bottom of much of Zone 2 was covered with ridges 0.02 m to 0.36 m high, and the birds used them as nest sites. Zone 1 and phases 1 and 2 were leveled prior to flooding to yield more evenly wet terrain, but the water cut channels and created dry alkali-crusted islands which provided abundant nest sites. By 2002, berms up to 1 m high were being constructed within zones 1 and 2 to increase ponding. These berms were also used as nest sites. Within a portion of Phase 1, 46 rectangular gravel islands of 193 m^2 each were constructed to provide plover nest sites. Water depth within the flooded areas ranged up to about 1 m, in areas where it collected in ponds for recycling. In 2002, the depth of water nearest nests averaged 0.037 m (standard error [SE] = 0.00, n = 68) versus 0.054 m (SE = 0.01, n = 35) at randomly selected points within Zone 2. Salinities in late May 2003 varied from 4 to 64 parts per thousand (ppt) in zones 1 and 2, 88 to 113 ppt in Phase 1, and 298 to 313 ppt in Phase 2 (CH2M Hill unpubl. data).

We divided the lakebed into west, north, east, and south/southeast survey regions that included natural seeps or (after 2001) artificially flooded areas where plovers were likely to congregate (Figure 1, Table 1). The west region included eight seeps; the north region the Owens River delta and, beginning in 2003, the 4.8-km^2 Zone 1 flooded area; the east region three natural seeps encompassed within the 31.0-km^2 Zone 2 flooded area by 2002; and the south/southeast region seven natural seeps and later the 1.6-km^2 Phase 1 and 3.4-km^2 Phase 2 flooded areas. Phase 1 was partially flooded in 2002 and, with Phase 2, was fully flooded by 2003.

The surveys for adult Snowy Plovers were conducted mid-nesting season 14 times from 1978 to 2004 (Page and Stenzel 1981, Page et al. 1991, Table 1). Surveys lasted up to 8 days (severe weather or dust storms aborted field days in some years), except in 1978, when 14 days (25 May–7 June) were required to familiarize surveyors with the lakebed's geography, to develop a survey protocol, and to conduct the survey. After 1978, ten surveys were conducted from 19 to 31 May, two from 9 to 17 May, and one from 3 to 7 June. Coverage was the same each year except for the Owens River delta (usually dry by late May), which was surveyed only twice prior to 2001 because of difficult access; Whiskey Springs and North Tubman seeps, small areas with large seasonal fluctuations in water availability which were not surveyed regularly until 2002; Swede's Pasture not until 1996; Southwest Seep not until 1995; and Olancha Pond any year it was completely dry (Table 1). Keeler Seep, not surveyed until 2001, was subsequently encompassed within the Zone 2 flooded area, as were Hutchinson Well and North Keeler Seep. The 1.8-km^2 GBUAPCD flooded area, a small experimental test site, was surveyed in 2000, the only year it was present.

One or two people, with binoculars and 20–60× spotting scopes, surveyed wet areas within each region for plovers, usually during early morning or evening hours when visibility was best. When possible, adjacent sites were covered on the same or consecutive days. Surveyors walked through or adjacent to large natural seeps, stopping every 100 to 300 m to scan shallow water and surrounding alkali flats for adults and broods. To cover

Table 1 Number of Adult Snowy Plovers on Surveys of Owens Lake, 1978–2004

	Year						
Location	1978	1988	1990	1994	1995	1996	1997
West shore							
Northwest Seep	33	2	5	5	20	7	12
Bartlett/Carroll Creek	42	20	24	4	1	23	11
North Cottonwood	17	24	6	21	18	37	26
South Cottonwood	33	8	17	20	25	43	32
Mineral Works	16	1	1	0	3	0	2
Permanente/Ash Creek	67	47	33	19	9	3	23
Cartago Creek	115	0	0	52	17	11	25
Olancha Pond	12	18	0	0	2	0	0
Subtotal	335	120	86	121	95	124	131
South/Southeast region							
Sulfate Well	37	6	8	0	1	8	21
Swede's Pasture	0	NS[c]	NS	NS	NS	0	16
North Tubman Seep	NS	NS	NS	NS	NS	NS	NS
Tubman Springs	11	6	8	0	3	1	3
Whiskey Creek	NS	4	NS	NS	NS	NS	NS
Dirty Socks	88[d]	40	27	4	15	18	10
Southwest Seep	NS	3	2	NS	5	0	0
Phase 1 shallow flood	NH	NH	NH	NH	NH	NH	NH
Phase 2 shallow flood	NH	NH	NH	NH	NH	NH	NH
Subtotal	136	59	45	4	24	27	50
East shore							
North Keeler Seep	15	1	0	NS	0	0	4
Keeler Seep	NS	NS	NS	NS	NS	NS	NS
Hutchinson Well	13	15	10	0	0	0	9
GBUAPCD flood	NH	NH	NH	NH	NH	NH	NH
Zone 2 shallow flood	NH	NH	NH	NH	NH	NH	NH
Subtotal	28	16	10	0	0	0	13
North shore							
Owens River delta	NS	NS	NS	NS	NS	9	9
Zone 1 shallow flood	NH	NH	NH	NH	NH	NH	NH
Subtotal	0	0	0	0	0	9	9
Total adults	499[f]	195[g]	141	125	119	160	203

[a]SE, standard error.

[b]NH, no habitat suitable for the Snowy Plover at the time of survey.

[c]NS, area not surveyed.

[d]26 of the 88 adults were in a pond on the south side of Highway 190 that has not been present on subsequent surveys.

[e]Z2, seep encompassed within Zone 2 after flooding, thus indistinguishable.

[f]1978 survey totals previously published (Page and Stenzel 1981).

[g]1988 survey total previously published (Page et al. 1991).

Year								
1998	1999	2000	2001	2002	2003	2004	Mean	SE[a]
5	3	6	5	2	3	4	8	2
6	9	16	6	3	14	1	13	3
16	14	5	6	15	18	24	18	2
8	18	15	10	28	6	16	20	3
0	0	0	0	0	0	0	2	1
0	6	0	8	4	0	13	17	5
27	4	2	23	4	17	20	23	8
0	0	0	0	0	NH[b]	NH	3	2
62	54	44	58	56	58	78	102	20
6	20	19	33	12	16	6	14	3
6	13	5	21	0	5	0	7	2
NS	NS	NS	NS	3	6	3	4	1
6	5	2	16	14	7	5	6	1
NS	NS	NS	NS	4	3	2	3	0
16	24	16	20	6	0	6	21	6
0	0	2	0	2	0	0	1	0
NH	NH	NH	NH	6	11	48	22	13
NH	NH	NH	NH	NH	0	4	2	2
34	62	44	90	47	48	74	53	9
0	2	3	0	Z2[e]	Z2	Z2	3	1
NS	NS	NS	7	Z2	Z2	Z2	7	0
5	0	13	8	Z2	Z2	Z2	7	2
NH	NH	8	NH	NH	NH	NH	8	0
NH	NH	NH	NH	152	224	325	234	50
5	2	24	15	152	224	325	58	27
NS	NS	NS	4	17	20	0	10	3
NH	NH	NH	NH	NH	51	181	116	65
0	0	0	4	17	71	181	21	13
101	118	112	167	272	401	658	234	45

large shallow flooded areas, observers walked parallel transects 250 to 500 m apart through wet mud, stopping to scan for plovers every 100 to 300 m. We covered small flooded areas by driving perimeter roads, stopping to scan for plovers every 100 to 300 m. Observers communicated with radios to ensure plovers between them were not double counted. Zone 2 required two to seven consecutive days to complete because of its large size and difficult terrain, while other areas required only one day. At small natural seeps, stationary observers scanned the outflow and surrounding flats every 5 to 10 minutes for about an hour, typically just before dusk. The maximum number of adults and broods seen during a scan was used

as the count for the area. To detect broods, observers looked for specific behavior of adults—particularly males standing alert, head bobbing, calling, or performing distraction displays—and watched from a distance for up to 20 minutes until chicks appeared. Broods may have been more detectable at natural seeps, where observers stood in one location for longer periods, than in artificially flooded areas, where chicks, especially larger ones, could run ahead of walking observers to avoid detection.

We found nests by searching for lone females or pairs and watching them from a distance for up to an hour until they returned to a nest or scrape. Nest searches were undertaken every seven to ten days from April through August in all dust-control areas in the east and south/southeast regions of the lake from 2001 to 2003, in the north region in 2001 and 2003, and within 1 km of natural seeps in the east and south/southeast regions and at Cartago Creek in the west region from 2001 to 2003. We also searched dry alkali areas away from seeps in the south/southeast region about once per month from April through June from 1999 to 2003. Our effort at nest searching was consistent from 2001 to 2003 but not in 1999 and 2000 when fewer full-time observers targeted limited areas. We used the global-positioning system (GPS) to map the coordinates of all nests, and we floated the eggs of complete clutches to estimate nest-initiation date. From 1999 to 2002, we estimated nest distance to water visually and by pacing, or by calculations from two GPS coordinates; when possible, we measured small distances with a meter stick.

Because water, with its associated invertebrate prey, is important to the quality of Snowy Plover nesting habitat, we examined the effect of local precipitation on the number of plovers on annual surveys. We then compared the total number of plovers in the four years of water releases with the ten years in which no water flowed onto the lakebed.

RESULTS

Abundance and Distribution of Adults

Numbers of Snowy Plovers at Owens Lake declined sharply from 499 adults in 1978 to 195 on the next survey in 1988 (Table 1). From 1990 to 2001, numbers ranged between 101 and 203 (mean = 138, SE = 11), then increased to 272 in 2002, 401 in 2003, and 658 in 2004 (Table 1), in concert with the commencement of flooding in 2002. Artificially flooded areas accounted for 58% of the birds detected in 2002, 71% in 2003, and 85% in 2004. Once these areas were available, numbers of adults in the north and east regions increased steeply, while numbers in the west region remained relatively stable. Over a longer period, numbers of birds at seeps in the west region declined from an average of 113 (SE = 7) between 1988 and 1997 to 58 (SE = 4) from 1998 to 2004 (Table 1). The 335 adults recorded in this region in 1978 were many more than in any other year and higher than the lakewide totals in all other years prior to flooding for dust control (Table 1). In the south/southeast region numbers of birds at natural seeps varied markedly, from 4 to 90 (mean = 44, SE = 8) between 1988 and 2001, with a high of 136 in 1978 (Table 1).

Numbers of adult Snowy Plovers at Owens Lake were not correlated with local precipitation (Spearman rank correlation, $\rho = 0.297$, $P = 0.15$, $t = 1.076$, df = 12), but total numbers were greater in all years when water was released than in any years when no water was released (Wilcoxon test, $U = 55$, $P = 0.001$, Figure 2).

Nest Placement

There is no information on the Snowy Plover's nest placement at Owens Lake prior to the lake's drying. Of 21 nests located in 1978, 16 were close to creeks or seeps, 4 were on a small island in a flooded area south of Highway 190, and 1 was in a vehicle track on the alkali flats (Henderson and Page 1979). Of 11 nests close to creeks, 6 were at the edge of or in openings of patches of salt grass (*Distichlis spicata*) and 5 were on barren alkali flats (Henderson and Page 1979). Distances from water averaged 12 m (SE = 4) for island nests and 118 m (SE = 35) for all others (PRBO unpubl. data).

Nests found in natural areas in the north, east, and south/southeast regions of Owens Lake between 1999 and 2002 were scattered on open dry alkali flats. In 105 of 164 cases (64%), they were near distinctive features such as dry washes, sparse patches of salt grass, rocks, woody debris, unimproved roadsides, or vehicle tracks. In 2003, three nests were found within Phase 1 on gravel islands created specifically for plover nesting. After 2001, nest placement appeared to be strongly affected by the presence of artificially flooded areas. In 2001, before flooding, Zone 2 accounted for 27% of the

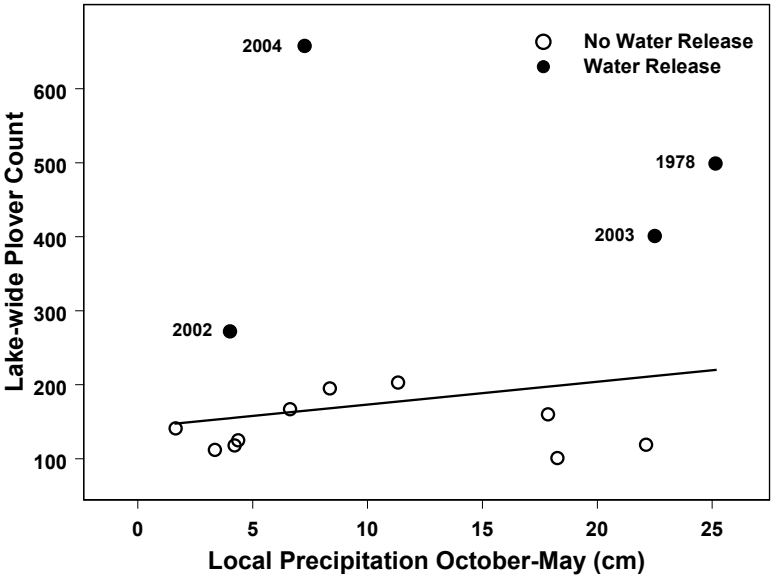

Figure 2. Relationship between numbers of Snowy Plovers, local precipitation rates, and large releases of water on the bed of Owens Lake.

98 nests found, whereas after flooding it accounted for 71% of 128 nests in 2002 and 61% of 199 in 2003 (Figure 1). In 2003, 80% of all nests we found were within the four artificially flooded areas (Figure 1). In 2002, distances of nests from water in natural areas in the east region, south/southeast region, and the Cartago Springs outflow averaged 425 m (SE = 72, n = 28), whereas in Zone 2 they averaged 8 m (SE = 1, n = 89). Prior to artificial flooding these distances averaged 468 m (SE = 83, n = 15) in 1999 and 379 m (SE = 38, n = 98) in 2001.

Abundance and Distribution of Broods

Like those of adults, numbers of Snowy Plover broods increased after flooding began in 2002. From 1988 to 2001, lakewide surveys averaged 14 broods (SE = 2) compared to 36 (SE = 2) from 2002 to 2004. Artificially flooded areas accounted for 45% of the lakewide total in 2002, 42% in 2003, and 72% in 2004. While most broods in flooded areas were probably from nests located within them, six broods were seen moving from the playa into Zone 2, and one brood from a nest in a managed vegetation plot moved into Phase 1. In late July 2003, when most natural sources of water were dry or significantly reduced in flow, all but 1 of 38 broods on a lakewide survey were in artificially flooded areas.

Phenology

The reflooding of the lakebed for dust control significantly extended the duration of the plover's breeding season at Owens Lake (Figure 3). Before flooding, or in natural areas after flooding began, few nests were initiated after the fourth week of May, whereas within the flooded areas over half the nests were initiated after the fourth week of May (χ^2 = 95, df = 2, P = 0.0). In 2001, 90% of 97 nests with known initiation dates had been initiated by the fourth week of May, as were an average of 92% of 75 nests in natural habitats in 2002 and 2003 (Figure 3). By comparison, in the artificially flooded areas an average of only 44% of 243 nests with known initiation dates had been initiated by the fourth week of May in 2002 and 2003 (Figure 3). In addition, prior to flooding, only 1% of the nests in 2001 were initiated in July, whereas in the flooded areas in 2002 and 2003 9% of the nests were initiated in July. The extension of the nesting season was likely not due to increased depredation rates because in 2002, when we checked nests in Zone 2 regularly, 86.7% of 90 clutches with known fates hatched (PRBO unpubl. data).

DISCUSSION

On the basis of regional surveys in 1978 and 1988 Page et al. (1991) identified Owens Lake as one of six key breeding sites for the Snowy Plover in the interior of California. The 499 adults on the 1978 survey coincided with large releases of water following a winter of heavy snowfall and was the highest count at any location. Despite smaller numbers after 1978, subsequent lakewide surveys demonstrated that Owens Lake continued to be an important breeding area for Snowy Plovers. From 1988 to 2001, in

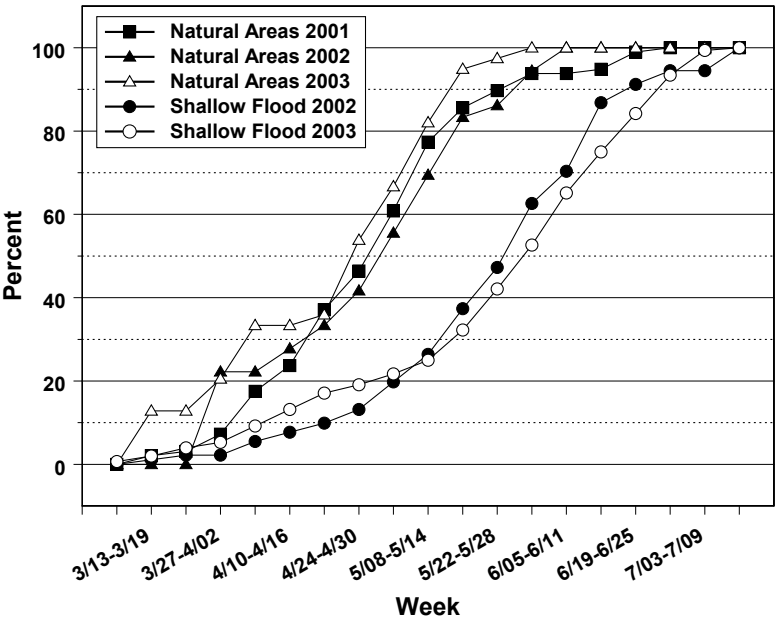

Figure 3. Cumulative percentage of Snowy Plover nests by initiation date. Numbers of nests were 97 in 2001, 36 in 2002, and 39 in 2003 for the natural areas, and 91 in 2002 and 152 in 2003 for the shallow flooded areas. See methods for more details.

the absence of large water releases, numbers of plovers varied from 100 to 200. Although annual local precipitation during that period varied by a factor of over 13, the variation was apparently insufficient to affect the number of breeding plovers. Flooding to reduce dust from 2002 to 2004 was accompanied by an immediate and sustained increase in plover numbers, suggesting that the creation of extensive shallow flooded areas was responsible for the rapid rise. The total of 658 adults in 2004 is to our knowledge the highest count for any location where the Snowy Plover breeds in California, coastal or interior.

While some plovers have probably been attracted to the new man-made habitat from other areas of Owens Lake, numbers in at least some natural areas, such as the west shore, have remained relatively stable during the period of lakebed alteration. The rates of increase in plover numbers at Owens Lake since initiation of flooding—63% from 2001 to 2002, 47% from 2002 to 2003, 64% from 2003 to 2004—are unlikely without emigration from other sites. An estimate of the number of young required for the population increases observed at Owens Lake, if it were a closed system with no emigration or immigration, and the annual survival rates were 0.50 for juveniles and 0.75 for adults (U. S. Fish and Wildlife Service

2001), can be estimated by solving for r_i from the equation $0.75 + 0.5r_i = n_{i+1}/n_i$, where r_i is the number of young fledged per adult in year i and n_i is the number of breeding plovers at Owens Lake in year i. The productivity necessary for the observed increases under these conditions is 1.8 young per adult (or 3.5–3.6 young per male) for the first and third intervals and 1.4 young per adult (2.9 young per male) for the second interval. These levels of productivity are likely quite a bit higher than the birds were able to achieve at Owens Lake, requiring population increases to be due in part to immigration from other areas

The source of the immigrating plovers is not apparent because of the absence of banded birds and the absence of comprehensive surveys of other inland nesting sites. At Mono Lake, 240 km north of Owens Lake, numbers on lakewide counts declined from 384 and 342 adults in 1978 and 1988, respectively, to 119 in 2001 and 98 in 2002 (Page et al. 1991, PRBO unpubl. data), during a period of shrinking shoreline nesting habitat as the water level increased. Without annual surveys at Mono Lake between 1988 and 2001, though, the timing and possible causes of the decline are uncertain (S. Heath pers. comm.). At the Salton Sea, 480 km south of Owens Lake, a count of 221 adults in late May 1999 (Shuford et al. 2004) was comparable to counts of 198 in 1988 and 226 in 1978 (Page et al. 1991). In the San Joaquin Valley the Snowy Plover population increased from fewer than 10 in the late 1970s to 241 in the late 1980s, paralleling the construction of 2870 hectares of evaporation ponds for agricultural waste water (Page et al. 1991, Roster et al. 1992). Subsequently, some ponds ceased operation and others were deliberately modified to make them less suitable for nesting because of a problem of excessive concentrations of selenium on nesting birds. We are uncertain how these changes have affected the Snowy Plover's numbers in the San Joaquin Valley as no comprehensive survey has been conducted since 1988.

The dust-control projects have created substantial new habitat for Snowy Plovers at Owens Lake. Since their initiation, numbers of adults and broods have more than doubled, nesting occurs nearer abundant food and water, and the nesting season lasts as long as on the coast (Warriner et al. 1986). The LADWP has spent millions of dollars implementing these projects and must continue to maintain them to be in compliance with federal air-quality standards. Almost constant irrigation of shallow basins requires large amounts of water—a scarce resource subject to many competing demands. Although protections to maintain minimum population levels of the plover are in place, as of 2004, the future of all but about 1000 acres (9.9%) of the 10,058 acres currently flooded is not guaranteed, as other less water-intensive methods of dust control may eventually prove more efficient. Snowy Plovers using artificially flooded areas at Owens Lake may be vulnerable not only to management changes over time but also to natural changes as the system evolves; for example, vegetation cover could increase in shallow flooded areas, reducing nesting habitat suitable for plovers. Continued monitoring of the plover population at Owens Lake will increase our understanding of the effects of continued dust control. Corresponding surveys of Snowy Plovers at other inland breeding sites would help identify intrinsic and extrinsic factors affecting future numbers of plovers at Owens Lake.

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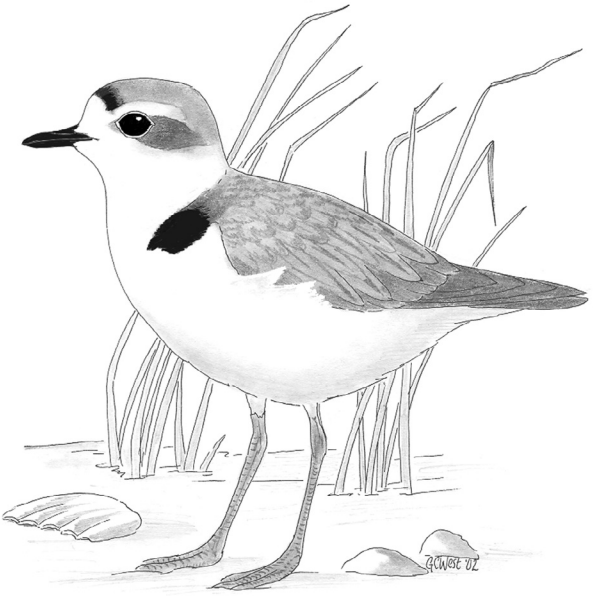

Snowy Plover

Sketch by George C. West