Final Report: 2010 Snowy Plover Breeding in Coastal Northern California, Recovery Unit 2

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Abstract.—*The Pacific coast population segment of the Western Snowy Plover (*Charadrius alexandrinus nivosus*) was listed as threatened under the U.S. Endangered Species Act in 1993. Here, we report on the 10th consecutive year of data collected to monitor the population that breeds in coastal northern California, one of six recovery units identified in the species' recovery plan. The number of breeding adults (31; 16 males and 15 females) in Recovery Unit 2 increased 63% over 2009 numbers. This increase resulted from unusually high adult breeding site fidelity (~100% of plovers that bred in 2009 returned to breed in 2010) and immigration of marked and unmarked plovers from elsewhere along the Pacific coast. Breeding plovers occupied eight locations; most (52%) plovers first bred at Clam Beach. Four philopatric yearlings (two breeding females; two breeding males) were detected, representing a high rate (44%) of return (survival) for the nine young that fledged in 2009. Plovers initiated 42 nests and hatched 24 chicks; 13 young fledged from four breeding sites. Overall, per capita reproductive success (average number of young fledged per male) was 0.81±1.22. Males breeding on gravel bars of the lower Eel River continued to have higher fledging success (3.00±0.00) than those occupying ocean-fronting beaches (0.31±0.63). Male cumulative reproductive success continued to be significantly lower for males on beaches than gravel bars. In 2010, plovers hatched 9 of 42 nests, a percentage (21%) slightly higher than in the previous two years (14%). We estimated daily predation rates (DPR) for nests established over the 10-yr period of intensive monitoring and determined that there was appreciable variation among sites. DPR was lowest on the gravel bars, and at remote beaches (Eel River Wildlife Area, Stone Lagoon) occupied by few plovers; conversely, DPR was consistently higher at Mad River Beach and Clam Beach. These results were supported by analyses of habitat and landscape features around nests on beaches, which showed a strong site effect: Clam Beach and Mad River Beach had appreciably lower daily survival rates than South Spit and Eel River Wildlife Area. Home ranges of male plovers on beaches (2773 m) were approximately double the size of those breeding on gravel bars (1250 m). Lastly, the activity of corvids (American Crow,* Corvus brachyrhynchos *and Common Raven,* C. corax*), as gauged by point counts conducted over the past five years indicated substantial spatial variation in danger posed to eggs and chicks. The lower gravel bars of the Eel River had especially high corvid activity whereas most beaches had lower activity; the exception to this occurred near picnic and access sites to beaches.*

Key words.—Charadrius alexandrinus nivosus, *corvid activity, daily predation rates*, *habitat quality, home range size, human disturbance, nesting success, predation, Recovery Unit 2, reproductive success, site fidelity, Western Snowy Plover.*

Introduction

For the tenth consecutive year, biologists from Humboldt State University (HSU) and Mad River Biologists (MRB) worked with county (Humboldt County Public Works), state (Department of Fish and Game, Department of Parks and Recreation), and federal (Bureau of Land Management, National Park Service, and United States Fish and Wildlife Service) staff and volunteers to monitor breeding activity of the Western Snowy Plover (*Charadrius alexandrinus nivosus*; hereafter plover) in coastal northern California (Del Norte, Humboldt, and Mendocino counties; USFWS Recovery Unit 2). In this report, we summarize our findings for the 2010 breeding season and interpret results in light of the species' recovery plan (USFWS 2007), as well as management and conservation actions in coastal northern California.

Background

In 1993, the federal government listed the coastal population of the Western Snowy Plover as a threatened population segment under the Endangered Species Act (USFWS 1993). In 1999, the USFWS designated critical habitat, an action that was renewed in 2004 following a lawsuit over failure to analyze the economic impacts of critical habitat designation. An economic analysis of the designation of critical habitat was produced in 2005. In 2001, the USFWS produced a draft recovery plan, which was recently finalized in 2007 (USFWS 2007). In 2006, the USFWS denied a proposal to de-list the plover based on a challenge to genetic distinctiveness of the population, despite contrary evidence (Funk et al. 2007). The USFWS did, however, propose a change to the management practices under the federal Endangered Species Act. The proposed 4(d) rule change would relax some management activities required by local jurisdictions for counties that exceeded (for 2 of 5 years) the number of breeding plovers as identified by the recovery plan (USFWS 2006).

The federal government listed the plover based on evidence of a significant population decline, as well as a reduction in the number of breeding locations along the Pacific coast of North America. The USFWS (1993, 2007) identified three factors that are thought to limit the population via negative effects on productivity or the number of young produced annually. These factors are: 1) increased development and human recreational

activity in beach habitats favored by breeding plovers; 2) predation of eggs and young by corvids (*Corvus brachyrhynchos*, *C. corax*), gulls (*Larus* spp.), red fox (*Vulpes vulpes*), raccoon (*Procyon lotor*), and striped skunk (*Mephitis mephitis*); and 3) degradation of nesting habitat by introduced plants such as European beach grass (*Ammophila arenaria*). Prior to listing, Page et al. (1991) estimated the California population at 1386 plovers, down 11 percent from the 1565 estimated a decade earlier (Page and Stenzel 1981). In 2010, a coordinated, week-long survey during the breeding season indicated that 1747 plovers occurred along the U.S. Pacific coast; this estimate was slightly greater than the previous three years, when numbers varied between 1537 (2007) and 1587 (2009). This estimate remains well below the population size of 3000 birds listed as a recovery objective (USFWS 2007), although some local population sizes have approached or surpassed recovery objectives for some areas (e.g., Monterey Bay).

In coastal northern California, plovers have bred and wintered along ocean beaches and gravel bars of the Eel River in each of the past 10 years (Colwell et al. 2010). In 2001, the USFWS designated Mendocino, Humboldt, and Del Norte counties as a discrete management unit (RU2). Surveys (Page and Stenzel 1981, Fisher 1992-94, LeValley 1999, McAllister et al. 2001, Colwell et al. 2009) indicate that most observations of breeding plovers occur in Humboldt County. In 1977, Page and Stenzel (1981) observed 64 birds (18 nests) at seven Humboldt County locations and estimated that this represented 6% of plovers breeding in coastal California. At this time, Humboldt County had more plovers than any location north of Monterey. During the early 1990s, Fisher (1992-94) surveyed Humboldt County beaches and recorded 22-32 plovers and 17-26 nests annually. In 1999, LeValley (1999) recorded 49 birds and 23 nests at four locations. In 2000, this same area supported about 40 adults and 42 nests (McAllister et al. 2001). Until recently, plovers had not been observed nesting in habitats other than along coastal beaches of northern California. However, in 1996 plovers were first recorded nesting on gravel bars of the lower Eel River (Tuttle et al. 1997). The Eel River remains a unique and productive breeding habitat. With the onset of intensive monitoring in 2001, we showed that most plovers in Humboldt County nested on Eel River gravel bars (Colwell et al. 2005a, 2010); this pattern, however, has been reversed in recent years. Both hatching and fledging success are consistently higher for river- than beach-breeding plovers (Colwell et al. 2005a, 2010).

In summary, over the past several decades the total number of breeding sites and breeding population in Humboldt, Mendocino, and Del Norte counties has decreased (USFWS 2007, Colwell et al. 2008). Recently, however, numbers in Humboldt County may have increased slightly with the discovery of plovers nesting on Eel River gravel bars (Tuttle et al. 1997). It is difficult, however, to address local population trends prior to 2001 since researchers surveyed different habitats with varying effort. Moreover, since plovers tend to disperse widely during the breeding season (Stenzel et al. 1994), it is likely that some individuals may be recorded as breeding in more than one location. Nevertheless, the population of Snowy Plovers breeding in RU2 remains at a low level compared to approximately five years ago, although the population increased in 2010 (see below).

Study Area

We studied plovers from mid-March to the end of August 2010 in coastal northern California. Most intensive monitoring occurred at eight locations in Humboldt County where observers detected breeding plovers. These locations included: Stone Lagoon, Clam Beach, Mad River Beach, South Spit, Eel River Wildlife Area, Centerville Beach, and the Worswick and Loleta gravel bars on the Eel River. Observers also regularly (i.e., weekly, bimonthly or window survey) monitored many other sites with suitable habitat.

Methods

We conducted research under federal (USFWS permit TE-823807-3; USFWS banding permits #22971 and #10457), state (Department of Fish and Game collecting permit #SC0496; Department of Parks and Recreation permit #08-635-011), and university (Humboldt State University IACUC #04/05.W.17-A) permits.

Banding. We captured and marked adult plovers with a unique combination of colored leg bands and colored tape (e.g., red, yellow, orange, green, violet, white or blue) wrapped around a USFWS metal band. At hatch, we marked chicks on the right leg with a single metal band wrapped with brood-specific colored tape to enhance knowledge of brood survival (Colwell et al. 2007a). When the hatching sequence of chicks was evident, we marked the colored tape attached to the metal band with the number 1, 2 or 3 denoting the order of hatch (and hence age) of chicks. Details of banding effort for 2010 are shown in Appendix 1.

Surveys. Observers surveyed suitable habitats for breeding activity beginning in mid-March and continuing until 29 August, when the last brood fledged. Most observations occurred at seven locations where we detected breeding plovers, although observers surveyed unoccupied sites a minimum of 9 times (at 7-10 day intervals) throughout the nesting season. Upon finding a nest, we noted the number of eggs in the clutch. For complete clutches, we floated eggs to determine stage of development and estimate hatching dates (Liebezeit et al.

2007). We recorded the location of each nest using a global positioning system (GPS). We monitored broods during regular surveys and confirmed that chicks had fledged by noting their presence at a site 28 days after they had hatched (Page et al. 1995). Observers also used adult behaviors to confirm that chicks had failed to survive, such as when we observed males (which usually tend chicks for 28 days after hatch) courting females before their chicks would have fledged.

Field Methods. During surveys, we collected data on the identity of marked adults incubating eggs or tending young (e.g., brooding, performing a distraction display), and we used this information to determine clutch ownership and reproductive success. We regularly monitored the status of nests, noting whether a clutch had failed or not. In the event of clutch failure, we determined probable cause to be: 1) predation (eggs disappeared prior to predicted hatch date, predator footprints occurred at a nest or egg shell fragments/yolk at nest); 2) drifting sand (coincident with strong winds, eggs partially or completely buried by sand); 3) tidal overwash (eggs displaced or absent from nest and recent high tide line situated above nest elevation); 4) human-caused (vehicle tracks or footprints pass directly over nest and eggs gone or egg remnants in nest cup); 5) dog-caused (tracks leading to nest cup and eggs gone); 6) abandoned (eggs untended as evidenced by absence of plover tracks over multiple days); or 7) unknown (eggs disappear from nest with no sign of causes listed above or we were unable to conclude the cause of failure because more than a day had elapsed since the last nest check). In the case of drifting sand, we could not easily discern when a clutch failed nor could we be certain that drifting sand caused failure. Moreover, in the case of incomplete clutches (i.e., found during the laying stage with one or two eggs), the general absence from the nest site of tending adults until the last egg was laid made eggs vulnerable to being covered by drifting sand. By contrast, during incubation, sand may drift over clutches when humans, dogs or vehicles disturb tending adults for long intervals.

Management Activities. For the first time since 2006, we used nest exclosures to protect eggs in two nests (South Spit and Eel River Wildlife Area) from vertebrate predators. In 2006, we made the decision to discontinue use of exclosures when evidence accumulated that an avian predator at Clam Beach killed at least one adult near an exclosure, and seven other adults disappeared during incubation. On 12 March and 27 August 2010, we coordinated with personnel from Humboldt County Department of Public Works, USFWS, and California State Parks to erect and take down, respectively, a symbolic fence for the seventh consecutive year. We erected the fence along a ~1.5 km (~8 ha) stretch of beach between the north and south parking lots accessing Clam Beach County Park. In previous years, plovers used this location for nesting and rearing broods. The management objective of the fence was to minimize human activities in the vicinity of breeding plovers (Wilson and Colwell 2010).

Data Summary and Analysis. Since the locations at which plovers bred differed in habitat and management issues, we collated data separately by location. We defined apparent nest success as the number of nests that successfully hatched at least one chick divided by the total number of nests. For each breeding location, we estimated daily predation rate of nests using Program MARK, determining the exposure period for each nest as follows: 1) for nests that were depredated or failed due to unknown causes (most of these were likely depredated as well), we determined the number of exposure days using the Mayfield (1975) method; 2) nests that ultimately failed owing to humans, tidal overwash, or drifting sand were censored at the last active nest check and coded as successful (since they were not depredated); 3) abandoned nests were censored on the day they were determined to be abandoned and coded as successful; 4) “nests” that were located at hatch or after hatch (i.e., as a brood of chicks) were assigned 33 exposure days (5 day laying period + 28 days of incubation) and coded as successful. We excluded from analyses nests protected by predator exclosures. From the number of broods hatched, we calculated brood success as the percentage of broods that had at least one chick reach 28 days age (i.e., post hatch). We calculated the number of fledged chicks per male to facilitate comparisons with population viability analyses published in the recovery plan (USFWS 2007). We used two-tailed t-tests to compare per capita fledging success between ocean (beach) and river (gravel bar) habitats; chi-square tests to examine differences in return rates of males and females; and nonparametric correlations to evaluate changes over time (yrs) in per capita reproductive success. We present data as means (±1 SD).

Results and Discussion

Population Size. After several years of decline, the population of plovers in RU2 increased by 63% to 31 breeding adults (Table 1). During the mid-May RU2 window survey, observers tallied 19 adults, most (89%) of which were in Humboldt County. This number was up slightly from the previous two years (2009=15; 2008=18) but it remains lower than in earlier years (2007=26; 2006=45; 2005=41) when the breeding population was larger. During the 2010 window survey, observers detected adult plovers at 6 sites (2 plovers at Stone Lagoon; 6 at Clam Beach, 2 on Mad River Spit, 4 on the Eel River Wildlife Area, 3 on the Worswick gravel bar, and 2 at McKerricker State Beach in Mendocino County). Window surveys represent a smaller number of the total

population because: 1) observers occasionally failed to detect some resident breeders during the single visit to each site, which is the protocol for the window survey; and 2) the window survey occurs during a brief interval midway through the breeding season; hence, it fails to account for individuals that either breed early and depart to breed elsewhere along the Pacific coast or those that arrive to breed late in the season.

Table 1. Annual variation in composition of the Snowy Plover population in Recovery Unit 2. Totals do not include non-breeding birds.

	Males					Females				
Year	Returning (marked) Adults	Returning (marked) Yearlings	Immigrants Banded Elsewhere	Unbanded Immigrants		Returning (marked) Adults	Returning (marked) Yearlings	Immigrants Banded Elsewhere	Unbanded Immigrants	Total
2010	9	2	4	1		9	1	4	1	31
2009	9	0	0	1		6	2	1	0	19
2008	10	2	3	3		6	2	6	5	37
2007	10	2	2	2		8	2	2	2	30
2006	16	6	4	3		13	4	4	7	57
2005	16	8	2	5		17	4	4	7	63
2004	17	5	4	11		16	4	6	11	74
2003	23	4	0	1		18	5	1	5	57
2002	17	8	0	5		19	6	1	4	60
2001	14	6	0	8		11	2	1	15	57

In 2000, prior to intensive monitoring, we began capturing plovers with the goal of marking all breeding individuals in RU2 by the end of each breeding season. Table 1 shows annual variation in the composition of the breeding population over the past 10 years, broken down into: a) marked yearlings recruited from the local population; b) site-faithful adults marked in RU2 in a previous year; c) marked immigrants from elsewhere along the Pacific coast; and d) unmarked birds, which are presumed to be immigrants from outside RU2. Over the past nine years (2002-10; when we were confident that we had marked nearly all breeding plovers in the previous year), population size tended to increase with the percentage of immigrants in the population. In 2010, the population included 10 immigrants (including one unmarked female and male), which represents a substantial increase over 2009) and a number comparable to the average of the earlier years when 30±13% of the population were immigrants. These data, coupled with analyses of survival and population growth (Mullin et al. 2010), indicate the continued importance of immigration to the RU2 population.

Philopatry and Site Fidelity. In 2010, nine adult males and 10 adult females returned to RU2 during the breeding season and exhibited breeding behavior; several yearlings (2 males and 1 female) also bred locally (Tables 1 and 2). We confirmed that most (97%) of these plovers bred locally; one adult female returned in July and courted a male on Clam Beach but we never found a nest. For adults, virtually all adults that bred in 2009 returned to breed in RU2 in 2010, including one female who was last observed breeding locally in 2008. Over the 10-year interval, males tended to return (59%) at a higher rate than females (50%) (Table 2; $X^2 = 3.70$, df = 1, P = 0.054). These return rates indicate that over-winter survival of adults was high and that comparatively poor reproductive success appears to have had little influence on breeding dispersal. For the second year, however, a pair that formerly bred on Clam Beach bred successfully at Stone Lagoon, although they initiated their first nest of the year on Clam Beach. With a ninth year of data, the overall return rate of chicks to the population remained slightly, but not significantly ($X^2 = 2.19$, df = 1, P = 0.14) male-biased. In total, 11.5% of females and 15.8% of males marked as chicks were philopatric (i.e., returned to breed in RU2).

Patch Occupancy. Since 2001, plovers have bred at 19 sites (8 beaches, 11 gravel bars on the Eel River) within Humboldt County; plovers have bred sporadically at several sites in Mendocino County; there are no recent records of plovers breeding in Del Norte County. Over the past 10 years, occupancy and density have varied markedly among the 19 breeding sites in Humboldt County (Burrell 2010). There has been a decline in both the percentage of the RU2 population and the number of occupied breeding sites along the gravel bars of the Eel River; by contrast, the percentage of the population occupying beach sites has increased gradually (Colwell et al. 2010). In 2010, plovers bred at eight locations (six beaches, two gravel bars) in RU2, all located in Humboldt County. The number of occupied sites increased over the past three years when plovers bred at 5-8 locations. Over the past nine years, two breeding sites, Worswick gravel bar and Clam Beach, have usually had the highest numbers of breeding plovers for river and beach sites, respectively; these two sites are the only ones to host breeding plovers each year since 2001.

Table 2. Annual variation in philopatry and site fidelity of Snowy Plovers in Recovery Unit 2.

		Females			Males	
	Year	Number Banded	Percentage Returned (n)		Number Banded	Percentage Returned (n)
Philopatry[a]	2010	7.5	13 (1)		7.5	27 (2)
	2009	7.5	27 (2)		7.5	13 (1)
	2008	21	9 (2)		21	9 (2)
	2007	27.5	7 (2)		27.5	7 (2)
	2006	35.5	11 (4)		35.5	17 (6)
	2005	38	11 (4)		38	16 (6)
	2004	30.5	13 (4)		30.5	20 (6)
	2003	34.5	14 (5)		34.5	12 (4)
	2002	46.5	13 (6)		46.5	17 (8)
	2001	29	7 (2)		29	24 (7)
	Total	277.5	11.5 (32)		277.5	15.8 (44)
Adult Site Fidelity[b]	2010	9	100 (9)		10	90 (9)
	2009	18	33 (6)		16	50 (8)
	2008	15	40 (6)		16	63 (10)
	2007	25	36 (9)		29	34 (10)
	2006	31	42 (13)		32	50 (16)
	2005	35	40 (14)		33	52 (17)
	2004	28	54 (15)		27	63 (17)
	2003	29	59 (17)		30	73 (22)
	2002	29	62 (18)		28	61 (17)
	2001	18	61 (11)		18	78 (14)

[a] Return of a locally-banded chick to breed in RU2; assumes an equal sex ratio at hatch (i.e., an odd number of chicks hatched in a previous year produces a non-integer value for the number of young of both sexes).

[b] Return of a breeding adult (with a known nest) to nest the next year. Individuals may be represented in multiple years; includes philopatric yearlings.

Productivity. In 2010, plovers breeding in RU2 initiated 42 nests, hatched 24 chicks, and fledged 13 young. Per capita reproductive success (based on fledged young per adult male) was 0.81±1.22. Plovers breeding on gravel bars exhibit significantly greater reproductive success than those on beaches, whether examined annually or over the lifetime of individuals (Fig. 1; Colwell et al. 2010). This pattern continued in 2010, with three males breeding on Eel River gravel bars each fledging three chicks, whereas 13 males breeding on beaches fledged an average of 0.31±0.63 chicks.

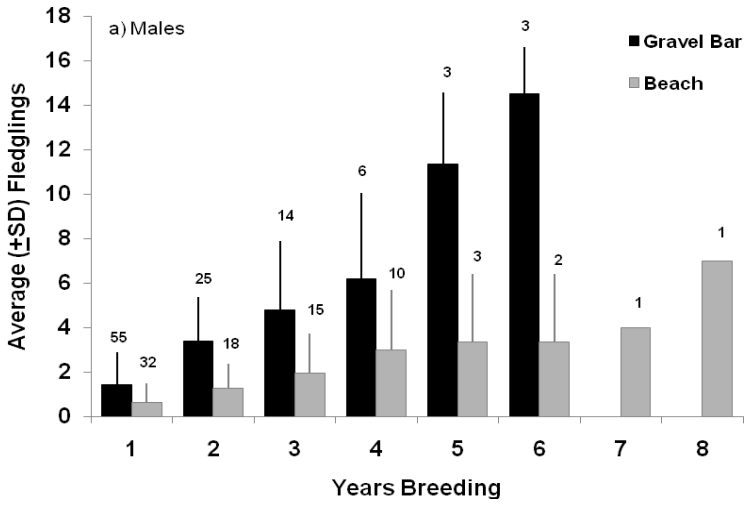

Figure 1. Mean (SD) cumulative reproductive success of male Snowy Plovers breeding on gravel bars was significantly greater than those on sandy, ocean-fronting beaches in RU2 (Colwell et al. 2010).

Table 3. A summary of distribution of breeding Snowy Plovers (percentage of adults) at locations in RU2.

	Year										Average
	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	±SD
Del Norte County	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Humboldt County											
Gold Bluffs Beach	0.0	0.0	0.0	2.4	3.0	0.0	0.0	0.0	0.0	0.0	0.5±1.1
Stone Lagoon	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0[a]	3.2	0.0±0.0
Big Lagoon	0.0	0.0	0.0	0.0	6.1	0.0	0.0	0.0	0.0	0.0	0.6±1.9
Clam Beach	16.4	28.6	37.7	40.2	48.5	52.5	56.3	67.6	63.2	51.6	46.3±15.7
Mad River Beach	0.0	0.0	0.0	0.0	0.0	0.0[a]	9.4[a]	0.0[a]	0.0[a]	6.5	1.6±3.4
Elk River	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0±0.0
South Spit	0.0	0.0	6.6	2.4	6.1	11.9[a]	0.0[a]	8.1[a]	0.0	0.0	3.5±4.4
Eel River Wildlife Area	18.0	17.5	1.6[a]	2.4	0.0	0.0	9.4[a]	10.8	15.7[a]	16.1	9.2±7.5
Centerville Beach	0.0	0.0	0.0	2.4	0.0	3.4	0.0	0.0	0.0	6.5	1.2±2.2
Eel River gravel bars	65.6	54.0	50.8	39.0	27.3	28.8	25.0	13.5	21.0	16.1	34.1 ±7.5
Mendocino County											
Brush Creek	0.0	0.0	0.0	4.9	3.0	3.4	0.0	0.0	0.0	0.0	1.1±1.9
Ten-mile Creek	0.0	0.0	3.3	7.3	3.0	0.0	0.0	0.0	0.0	0.0	1.4±2.5
Virgin Creek	0.0	0.0	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.3±0.9
Total Breeding Plovers	61	63	61	82	66	59	32	37	19	31	

[a] Individuals were counted only once per year (at their first breeding site), despite nesting at up to three locations within a year.

Reproductive Success. Apparent nesting success of plovers in RU2 has varied substantially over the 10 years of intensive monitoring (Table 4 and 5). Over the past 10 years, 36.5% of 559 nests hatched at least one chick. Hatching success has varied annually from 14-68%, with the lowest success in 2008 and 2009. A decline in hatching success since 2001 (r_s=-0.85, P=0.002) parallels a shift in distribution of breeding plovers away from highly productive habitats along the Eel River to ocean-fronting beaches. High nesting success of plovers breeding along the Eel River is attributable to natural crypsis afforded eggs by coarse substrates (Meyer 2005, Colwell et al. in prep.). Conversely, in recent years low hatching success coincides with three years in which we did not use predator exclosures to protect nests; this year, we erected exclosures at two nests. Predation was the leading cause of nest failure and video camera evidence (Colwell et al. 2009) at Clam Beach showed that Common Ravens were the main egg predator. As in years past, our estimate of the contribution of predation to nest failure is conservative because the "unknown" category includes many situations in which eggs disappeared and there was no clear evidence of the cause of failure (e.g., corvid tracks at the nest). It is reasonable to conclude, however, that most of the nests failed owing to predation.

Overall, males fledged 0.81±1.22 chicks, which is below the level necessary to maintain the population (USFWS 2007). It also represents a pattern of low and declining productivity over the past 10 years (0.90, 1.7, 0.8, 1.1, 1.2, 0.9, 0.7, 0.7 and 0.5 fledged chicks per male for 2001-09, respectively). Plovers breeding on ocean beaches continued to exhibit low fledging success (0.31±0.63 fledglings per male) compared to those breeding on gravel bars of the Eel River (3.00±0.00). In each of the preceding nine years, plovers on the Eel River have fledged significantly more young than those breeding on ocean-fronting beaches (Colwell et al. 2005a, 2010).

Daily Predation Rates. As predation is the leading known cause of nest failure in RU2 (Table 5), we estimated daily predation rates (hereafter DPR) in order to better compare the relative impact of predation on nest survival among sites and between years. We treated nests that failed due to unknown causes the same as known predation events, since the majority of these nests were probably depredated (Colwell et al. 2009). We also included nests that ultimately failed due to other known causes, although these nests were coded as successful (see Methods, above); we felt that these nests should be included (since they were exposed to the threat of predation while active), but not treated as failures (since they were not depredated). In order to avoid biasing our DPR estimates low, we only considered unexclosed nests. Note, however, that we made a concerted effort to exclose as many beach nests as possible during the first five years of the study and many unexclosed beach nests were only unexclosed because they failed quickly, before biologists could protect them. Thus, beach DPR estimates from 2001-2005 may actually be biased high, particularly at Clam Beach. Beach estimates from 2006-2010 (and all river estimates, as river nests were never exclosed) should not suffer from this same bias.

Table 4. Summary of Snowy Plover breeding in Recovery Unit 2 in 2010 with comparison to 2000-09.

Location		Females[a]	Males[a]	Number of Nests	Number Exclosed	% Nests Hatched[b]	# Chicks Hatched	# Chicks Fledged[c]
Del Norte County		0	0	0	0	0	0	0
Humboldt County								
Gold Bluffs Beach		0	0	0	0	0	0	0
Stone Lagoon		1	2	3	0	67	4	3
Big Lagoon		0	0	0	0	0	0	0
North Clam Beach and LRSB		5	6	12	0	8	3	0
South Clam Beach		6	5	12	0	0	0	0
Mad River Beach		2	2	3	0	0	0	0
South Spit Beach		1	1	1	1	100	3	0
ERWA		3	4	5	1	40	5	1
Centerville Beach		1	1	1	0	0	0	0
Eel River Gravel Bars		4	4	5	0	50	9	9
Cock Robin Island		0	0	0	0	0	0	0
Fulmor		0	0	0	0	0	0	0
Roper's		0	0	0	0	0	0	0
Singley		0	0	0	0	0	0	0
Loleta		3	3	4	0	50	6	6
Fernbridge		0	0	0	0	0	0	0
Worswick		1	1	1	0	100	3	3
Drake		0	0	0	0	0	0	0
Canaveri Island		0	0	0	0	0	0	0
Mercer-Fraser		0	0	0	0	0	0	0
Sandy Prairie		0	0	0	0	0	0	0
Mendocino County		0	0	0	0	0	0	0
Brush Creek		0	0	0	0	0	0	0
Tenmile River		0	0	0	0	0	0	0
Virgin Creek		0	0	0	0	0	0	0
RU2 Total	2010	15	16	42	2	21	24	13
	2009	9	10	35	0	14	15	9
	2008	14	16	50	0	14	15	8
	2007	14	16	41	0	22	21	11
	2006	28	29	58	19	34	55	20
	2005	31	32	57	27	47	71	28
	2004	37	35	70	28	43	76	39
	2003	27	27	74	23	38	64	32
	2002	30	33	75	25	40	76	23
	2001	31	29	57	13	68	97	46
	2000	--	--	42	18	64	58	--

[a] Based on histories of marked birds with known nests. Some individuals are assigned to multiple sites (e.g., Stone Lagoon, Clam Beach, Mad River Beach, South Spit, Eel River Wildlife Area, Loleta, Worswick and Centerville).

[b] Apparent nest success = number of nests that hatched at least 1 chick / total nests.

Overall, nests on Eel River gravel bars experienced lower DPR than beach nests, although there were some exceptions (Table 6). DPR was particularly high at Clam Beach (0.065-0.390) and Mad River Beach (0.051-0.157), but nests at more remote beach sites (e.g., Stone Lagoon, Big Lagoon, and South Spit) or beaches with greater amounts of cryptic nesting habitat (e.g., Eel River Wildlife Area) generally experienced lower predation rates similar to those found on gravel bars. Worswick, the only gravel bar occupied during each of the past ten years, had consistently low DPR (0.000-0.027); in contrast, the Fulmor gravel bar had DPR comparable to, or higher than, that found at Clam and Mad River Beaches (0.137-0.905) in the years when plovers nested there. It is worth noting that observers regularly detected large aggregations of foraging and roosting corvids while surveying the Fulmor gravel bar (see below); DPR suggests that corvid predation may overwhelm the beneficial effects of cryptic, high-quality nesting habitat (Meyer 2005, Hardy 2010). Finally, DPR at the Loleta gravel bar may offer additional insight into plover nest site selection and site fidelity: Plovers nested on Loleta for each of the first six years of intensive monitoring, but following a season of exceptionally high DPR in 2006 (0.218), plovers ceased nesting at this site and Loleta had remained unoccupied until 2010.

Table 5. Annual variation in Snowy Plover nesting success[a] and causes of clutch failure in Recovery Unit 2.

	2001		2002		2003		2004		2005		2006		2007		2008		2009		2010	
Clutch Fate	**N**	**%**	**N**	**%**	**N**	**%**	**n**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**
Hatched	39	68	29	39	28	38	30	43	27	47	20	34	9	22	7[b]	14	5	14	9	21
Failed and cause																				
Predation	4	7	12	16	17	23	18	26	7	12	11	19	11	27	14	28	11	31	8	19
Abandoned	2	4	4	5	5	7	9	13	4	7	8	14	1	2	2	4	0	0	1	2
Sand covered	1	2	7	9	6	8	4	6	4	7	0	0	2	5	2	4	2	6	0	0
Tidal overwash	0	0	2	3	4	5	1	1	2	4	0	0	0	0	0	0	2	6	2	5
Human	0	0	7	9	5	7	3	4	0	0	3	5	2	5	3	6	4[b]	11	0	0
River flood	0	0	0	0	5	7	0	0	4	7	0	0	0	0	0	0	0	0	0	0
Unknown	11	19	14	19	4	5	5	7	9	16	16	28	16	39	22	44	11	31	22	52
Total Nests	57		75		74		70		57		58		41		50		35		42	

[a] Apparent nesting success = 100[number of nests hatching at least one chick / total number of nests].

[b] Includes: 1) a nest on Clam Beach in which humans took 3 eggs; 2) two additional Clam Beach nests destroyed by unleashed dogs; and 3) a nest on Worswick that was crushed by a vehicle.

Table 6. A summary of daily predation rates[a] at breeding sites in RU2, 2001-10.

	Year									
	2001	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Del Norte County	-	-	-	-	-	-	-	-	-	-
Humboldt County										
Gold Bluffs Beach	-	-	-	-	0.080	-	-	-	-	-
Stone Lagoon	-	-	-	-	-	-	-	-	0.000	0.000
Big Lagoon	-	-	-	-	0.000	-	-	-	-	-
Clam Beach[a]	0.065	0.390	0.184	0.264	0.125	0.080	0.094	0.098	0.082	0.107
Mad River Beach	-	-	-	-	-	0.157	0.051	0.146	0.110	0.142
South Spit[a]	-	-	-	-	-	0.000	0.000	0.029	-	-
Eel River Wildlife Area[a]	0.905	0.038	0.000	-	-	-	0.000	0.031	0.031	0.032
Centerville Beach	-	-	-	0.000	-	0.000	-	-	-	0.999
Eel River gravel bars										
Sandy Prairie	-	0.000	0.000	-	-	-	-	-	-	-
Mercer Fraser	-	-	-	0.020	-	-	-	-	-	-
Canaveri Island	0.937	0.000	0.094	-	-	-	-	-	-	-
Drake	0.000	-	-	-	-	-	-	-	-	-
Worswick	0.019	0.014	0.018	0.027	0.014	0.018	0.011	0.000	0.018	0.000
Fernbridge	-	0.000	0.000	-	-	0.000	-	-	-	-
Loleta	0.031	0.095	0.045	0.017	0.024	0.218	-	-	-	0.044
Singley	0.000	0.077	0.000	-	-	-	-	-	-	-
Roper's	0.000	0.000	0.000	0.060	-	-	-	-	-	-
Fulmor	0.905	-	-	0.137	-	-	-	-	-	-
Cock Robin Island	-	-	0.000	0.035	-	-	-	-	-	-
Mendocino County	-	-	-	*1.000*	-	*0.000*	-	-	-	-

[a] Daily predation rates calculated using the Mayfield (1975) method, including exposure days for nests that failed owing to human causes, tidal overwash and drifting sand. During years (2001-06; 2010) in which we used exclosures to protect eggs from predation, we excluded protected nests from estimate calculations.

In summary, patterns of DPR indicate that: 1) nests on remote beaches and most Eel River gravel bars experience lower predation rates relative to Clam and Mad River beaches; 2) concentrated corvid activity can render otherwise high-quality nesting sites unsuitable; and 3) high levels of nest predation may influence nesting behavior (i.e., prompt plovers to disperse). Nevertheless, there continues to be a shift in the distribution of breeding plovers from the Eel River to Clam and Mad River beaches over the past 10 years. Given the strong negative impact of corvid predation on plover eggs and chicks, this trend is cause for concern. Taken together, these data suggest two alternative (but not mutually exclusive) strategies to aid recovery of the RU2 population: 1) encourage plovers to settle at sites with lower DPR, by allowing high nest predation rates to gradually "push" breeding birds into higher-quality sites and/or modifying those sites to make them more attractive; and 2) reducing DPR at sites with aggregations of breeding plovers (specifically, Clam and Mad River beaches) through enhanced predator management.

Nest Survival Analyses. We used data collected on point counts and ground plots to investigate the influence of habitat characteristics on the daily survival rate (DSR; the probability of a nest surviving for 1 day) of

plover nests on ocean-fronting beaches. In order to avoid biasing our DSR estimates high (see Hardy and Colwell 2008), we only analyzed data from years in which nests were not protected by predator exclosures (i.e., 2007-2009). We conducted this analysis in 2 phases: 1) "preliminary" analysis using data from 2007 to identify the most informative subset of covariates (see Hardy 2010), and 2) "final" analysis using those covariates to develop a parsimonious *a priori* set of models to fit to data from 2008-2009. All DSR analyses were conducted using Program MARK.

Preliminary analysis suggested that DSR differed between sites in 2007. DSR also varied over the course of the breeding season; this variation was best described by a quadratic time trend (i.e., DSR started low, peaked mid-season, and declined somewhat later in the season). The five other most informative covariates were derived from point counts/ground plots within 100m of each nest (Table 7). There was no evidence to support annual differences in DSR, so we pooled data from 2008-2009 for the final analysis.

Table 7. The five most informative covariates from preliminary analysis, utilizing Snowy Plover nest data collected in 2007.

Covariate	Definition
Dog tracks	Incidence [a] of dog tracks on 3 m ground plots within 100 m of a nest
Corvid	Incidence [a] of corvid detections on 500 m point counts within 100 m of a nest
Vegetation	Incidence [a] of vegetation on 3 m ground plots within 100 m of a nest
H'	Diversity [b] of cryptic debris[c] on 3 m ground plots within 100 m of a nest
Clutter	Mean incidence of cryptic debris[c] on 3 m ground plots within 100 m of a nest

[a] Incidence = the proportion of point counts or ground plots with ≥1 detection.
[b] Diversity = Shannon-Wiener index.
[c] Includes stones, small woody debris, mollusk shells, crustacean carapaces, and *Velella*.

In 2008-2009, DSR varied across the season and among sites: DSR was high on South Spit (SS; range: 0.9868-0.9940) and at the Eel River Wildlife Area (ERWA; range: 0.9141-0.9592) and low at Clam Beach (CB; range: 0.7872-0.8911) and Mad River County Park (MR; range: 0.7684-0.8800). The final model that received the most support also included a site effect, a quadratic time trend, H' (i.e., debris heterogeneity), and "clutter" (i.e., amount of debris) (Table 8). The site effect was most pronounced, with positive significant coefficient estimates for SS and ERWA; this indicates that nests survive longer on these beaches compared to Clam Beach. MR had a small negative coefficient estimate, suggesting slightly lower DSR relative to CB, but this estimate was not statistically significant. H' had a significant positive coefficient estimate, suggesting that greater debris heterogeneity within 100 m of nests had a positive influence on DSR. In contrast, clutter had a significant negative coefficient estimate, suggesting that more debris within 100 m of nests negatively influenced DSR.

Table 8. Coefficient estimates and associated 95% confidence intervals from the highest-ranked models examining variation in Snowy Plover nest survival, 2008-09.

Covariate	Estimate	Lower 95% CI	Upper 95% CI
Intercept	1.6325	-0.06377	3.9026
Eel River WA[a]	1.0564	-0.2105	2.3233
Mad River[a]	-0.1090	-1.0423	0.8242
South Spit[a]	3.0086	0.7984	5.2188
H'	2.4408	0.2834	4.5983
Clutter	-1.5317	-2.6434	-0.4199
T[b]	0.0160	-0.0207	0.0527
TT[b]	-0.0001	-0.0003	0.0001

[a] Site effect: the coefficient estimate compares each site with nest survival at Clam Beach.
[b] T and TT represent a linear and quadratic time trend in nest survival over the breeding season, respectively.

Home Range Analyses. In each of the past six years, observers have used PDAs equipped with GPS technology to record the location of color-marked plovers and their nests during regular surveys of beach and gravel bar habitats. Here, we present preliminary analyses of home range for selected male plovers with sufficient data (Fig. 2). We estimated home range size as the straight-line distance across the 90% utilization distribution as determined with fixed kernel density estimation using least-squares cross validation for bandwidth selection (Brindock 2009). Where multiple areas of use described an individual's home range within a year, we summed the lengths of those areas to estimate home range as a linear stretch of beach or gravel bar. In some cases, least-squares cross validation could not determine the bandwidth, which resulted in a positively biased smoothing parameter and an inflated home range. In those instances, we omitted from analyses the data for

that year for the individual. For each individual-year, we plotted their nests in a GIS and determined whether or not the nest fell within the calculated home range as determined by the locations where males were observed during regular surveys.

We estimated home range size for 21 plovers (total sample was 33 because some birds provided data from multiple years), including 10 that bred on beaches and 11 that bred on gravel bars. Average home range size for male plovers breeding on beach sites (2773 m) was significantly greater ($t_{25,\ 8} = 5.86$, $p < 0.001$) than those on gravel bars (1250 m). Overall, 82.5% (n = 47) of beach nests and 90.0% (n = 18) of gravel bar nests were located within the 90% utilization distribution of the male's home range.

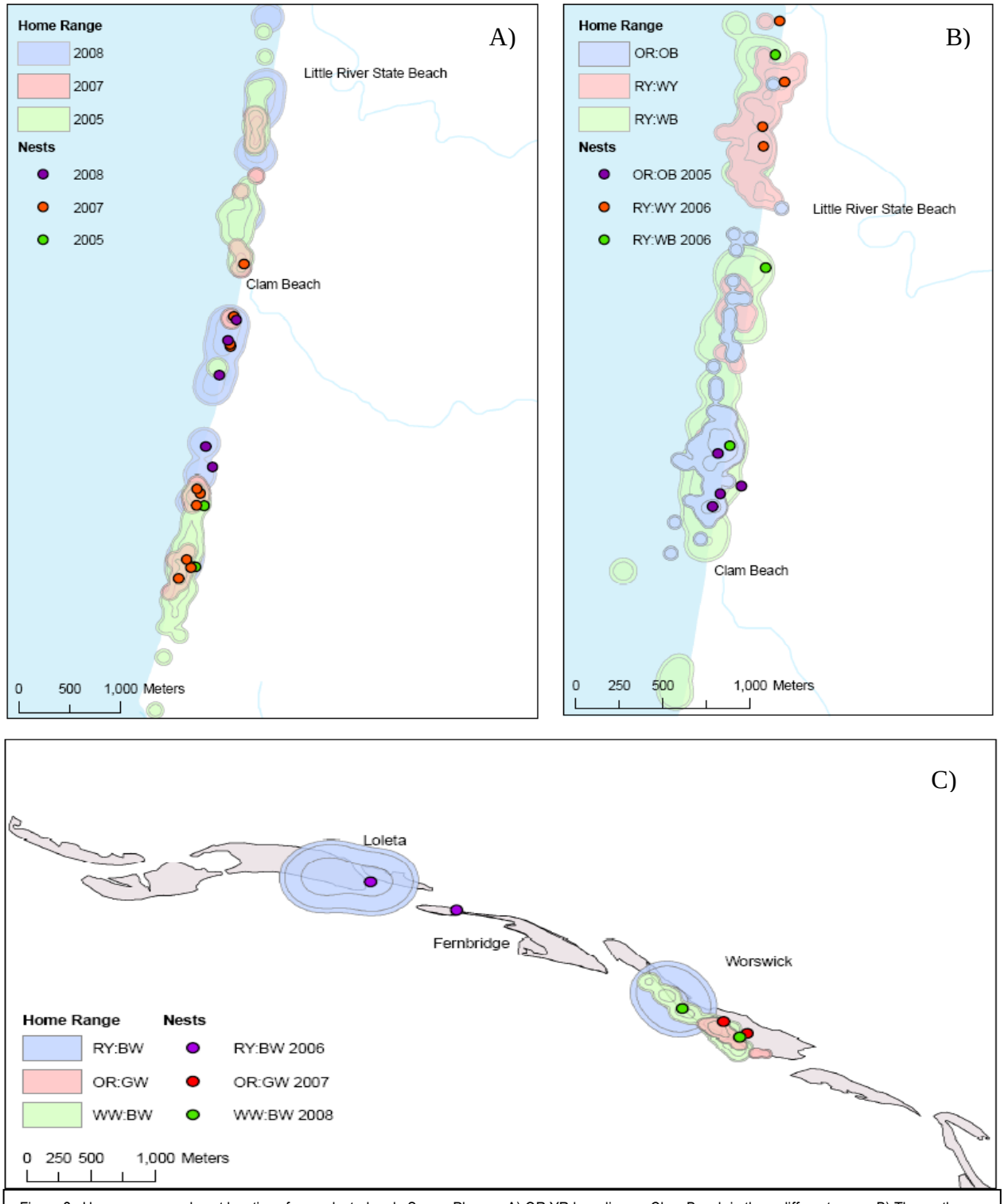

Figure 2. Home ranges and nest locations from selected male Snowy Plovers. A) OR:YR breeding on Clam Beach in three different years; B) Three other males breeding on Clam Beach, 2005-06; and C) three gravel bar breeding males, 2006-2008.

Corvid Activity Patterns. In an effort to understand relationships between plover productivity and activity of the principal predators of plover eggs and chicks, we used a GIS to map point count data (number of Common Ravens and American Crows observed within 500 m of an observer). These data are presented in Fig. 3. Corvid activity was lower on beaches than on gravel bars, especially those sites nearer the up-river end of Cock Robin Island where extremely high numbers of American Crows occurred. High crow activity on these gravel bars may be related to proximity to night-time roosts. On beaches, corvid activity was higher on Clam Beach and Mad River Beach than Eel River Wildlife Area and Centerville Beach. Within the former sites, however, the highest levels of corvid activity occurred predictably near sites where humans picnic, camp or access the beach. For instance, at Mad River County Park, high Common Raven activity occurred due west of the parking lot where humans commonly picnicked and left garbage that attracts scavenging birds.

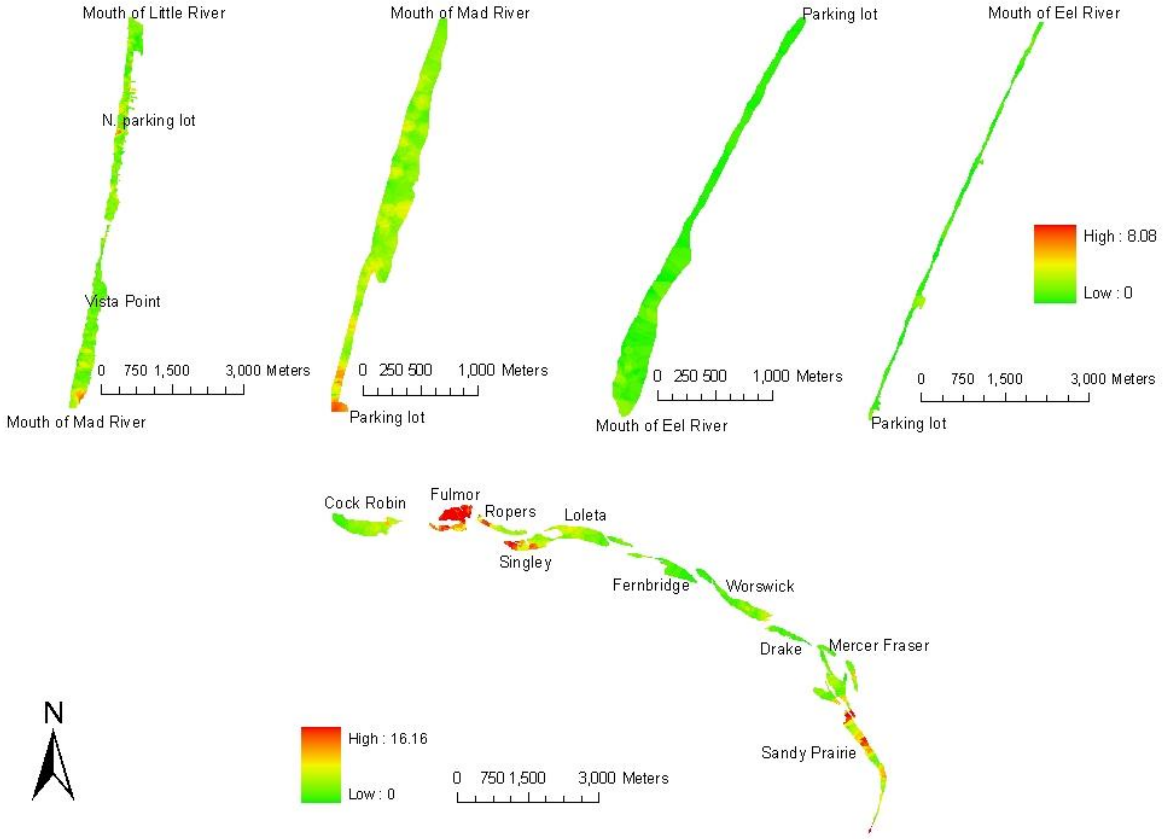

Figure 3. Spatial variation in corvid activity within Snowy Plover breeding sites based on the average number of corvids (American Crow and Common Raven) observed per point count, 2006-2009. From left to right in the top panel the sites are: Clam Beach, Mad River Beach, Eel River Wildlife Area, and Centerville Beach; the various gravel bars of the lower Eel River are shown in the bottom panel. Note that the scale indicating corvid activity differs between ocean-fronting beaches (0-8.08) and gravel bars (0-16.16).

Conclusions

In 2010, the population size of Snowy Plovers in RU2 (31 breeding adults) increased by 63% over 2009 (19), which was the lowest since intensive monitoring began in 2001. This year, plovers bred at eight locations in RU2, all in Humboldt County. This increase resulted from a large number of immigrants and comparatively high over-winter survival of adults and juveniles, as evidenced by the high return rates of both age groups to breed locally. The total number of young produced was slightly higher in 2010 (13 fledged young) compared with 2009 (9 fledglings). However, per capita reproductive success (0.81±1.22 fledglings per male) continues to be low, and this estimate is below the level necessary to grow the population.

Our conclusions about the relative importance of limiting factors contributing to the low population size and poor productivity of plovers in RU2, as well as management actions necessary to ameliorate these conditions, remain unchanged from those outlined in previous annual reports (e.g., Colwell et al. 2009). Therefore, we refer to those reports for details on management of 1) predators, 2) humans, and 3) habitat. In conclusion, however, we reiterate the relative importance of addressing these factors in the order that they are listed above.

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Appendix 1. Details of 2010 banding effort in Recovery Unit 2.

Band Number (USFWS)	Location	Color Band	Sex	Age	Date Banded	Nest Code	Notes
8021-23434	Stone Lagoon	X:W	Unknown	HY	29 May 2010	10SL02	
8021-24055	Stone Lagoon	X:B	Unknown	HY	7 July 2010	10SL03	
8021-24056	Stone Lagoon	X:B	Unknown	HY	7 July 2010	10SL03	
8021-24057	Stone Lagoon	X:B	Unknown	HY	7 July 2010	10SL03	
8021-24061	Clam Beach	X:Y	Unknown	HY	28 July 2010	10CN12	
8021-24062	Clam Beach	X:Y	Unknown	HY	28 July 2010	10CN12	
8021-24063	Clam Beach	X:Y	Unknown	HY	28 July 2010	10CN12	
8021-24051	Clam Beach	WW:BG	Male	AHY	25 June 2010	10CS07	
8021-24049	Eel River WA	VW:WR	Male	ASY	15 May 2010	10ES03	Formerly banded X:R; 8021-24022
8021-24050	Eel River WA	VW:WW	Female	AHY	15 May 2010	10ES02	
8021-24034	Eel River WA	X:Y	Unknown	HY	12 June 2010	10ES02	
8021-24035	Eel River WA	X:Y	Unknown	HY	12 June 2010	10ES02	
8021-24037	Eel River WA	X:Y	Unknown	HY	16 July 2010	10ES04	
8021-24038	Eel River WA	X:Y	Unknown	HY	16 July 2010	10ES04	
8021-24039	Eel River WA	X:Y	Unknown	HY	16 July 2010	10ES04	
8021-23436	South Spit	X:R	Unknown	HY	24 July 2010	10SS01	
8021-23440	South Spit	X:R	Unknown	HY	24 July 2010	10SS01	
8021-23441	South Spit	X:R	Unknown	HY	24 July 2010	10SS01	
8021-24052	Worswick	X:R	Unknown	HY	29 June 2010	10GW01	
8021-24053	Worswick	X:R	Unknown	HY	29 June 2010	10GW01	
8021-24054	Worswick	X:R	Unknown	HY	29 June 2010	10GW01	
8021-24048	Loleta	VW:YG	Female	SY	27 May 2010	10GL01	Formerly marked X:G
8021-24058	Loleta	X:G	Unknown	HY	13 July 2010	10GL03	
8021-24059	Loleta	X:G	Unknown	HY	13 July 2010	10GL03	
8021-24060	Loleta	X:G	Unknown	HY	13 July 2010	10GL03	
8021-24064	Loleta	X:R	Unknown	HY	2 August 2010	10GL04	
8021-24065	Loleta	X:R	Unknown	HY	2 August 2010	10GL04	
8021-24066	Loleta	X:R	Unknown	HY	2 August 2010	10GL04	
8021-24067	Loleta	VW:YB	Male	AHY	2 August 2010	10GL04	
2271-08248	Clam Beach	VW:YW	Male	SY	26 April 2010	10CS02	Formerly R/Y/R:G
2381-00893	Clam Beach	VW:WY	Male	AHY	21 June 2010	-	Formerly A/W:G
2381-00868	Clam Beach	VW:GG	Female	AHY	19 June 2010	10CS07	Formerly G/O:G
2381-00887	South Spit	GY:OW	Male	AHY	25 June 2010	10SS01	Formerly G/B/G:G

Appendix 2. List of papers, presentations of oral papers at professional meetings, graduate and undergraduate theses, 2009-10.

Scientific Papers

Wilson, C.A., and M.A. Colwell. 2010. Movements and fledging success of Snowy Plover (Charadrius alexandrinus) chicks. Waterbirds 33:331-340.

Muir, J. J., and M. A. Colwell. 2010. Snowy Plovers select open habitats for courtship scrapes and nests. Condor 112:507-510.

Mullin, S., M.A. Colwell, S.E. McAllister, and S.J. Dinsmore. 2010. Apparent survival of adult and juvenile Snowy Plovers in coastal northern California. Journal of Wildlife Management. In press.

Colwell, M.A., N.S. Burrell, M.A. Hardy, K. Kayano, J.J. Muir, W.J. Pearson, S.A. Peterson, and K.A. Sesser. 2010. Arrival times, laying dates, and reproductive success of Snowy Plovers in two habitats in coastal northern California. Journal of Field Ornithology 81:000.000.

Brindock, K.M., and M.A. Colwell. Habitat selection by wintering Snowy Plovers in coastal northern California. Journal of Wildlife Management. In press.

Colwell, M.A., J.J. Meyer, M.A. Hardy, S.E. McAllister, A.N. Transou, R.R. LeValley, and S.J. Dinsmore. In revision. Snowy Plovers Charadrius alexandrinus nivosus select substrates for nesting that enhance egg crypsis and influence nest survival. Ibis.

Colwell, M.A., J.J. Muir, and R.R. Thiem. Documenting causes of Snowy Plover nest failure using video cameras. Wader Study Group Bulletin. In prep.

Nelson, Z.J., and M.A. Colwell. Social attraction in breeding Snowy Plovers. Wilson Journal of Ornithology. In revision.

Panza, C.S., C.J. Dugaw, M.A. Colwell, and E.A. Burroughs. A model to assess the use of nest exclosures for local population recovery of the Western Snowy Plover (Charadrius alexandrinus nivosus). Natural Resource Modeling. In revision.

Presentations

Pearson, S., D. Lauten, and M.A. Colwell. Occupancy and detection probabilities for Snowy Plovers during the breeding season. Recovery Meeting for Snowy Plover. January 2010. Portland, OR.

Burrell, N.S. Breeding patch dynamics of Snowy Plovers in Humboldt County, CA. 11 August 2010. Humboldt State University, Arcata, CA.

Kayano, K., and M.A. Colwell. A comparison of female Snowy Plover reproductive effort in two habitats. September 2009. National meeting of SACNAS, Dallas, TX.

Graduate Thesis

Burrell, N.S. 2010. Patch dynamics of Snowy Plovers breeding in coastal northern California. M.Sc. thesis, Humboldt State University, Arcata, CA.

Workshops

LeValley, R.R. Snowy Plover training. BLM office, Arcata, CA. 8 June 2010.

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