Point Blue Conservation Science

Reproductive Success and Breeding Population Size of Snowy Plovers in the Monterey Bay Region in 2023

Final Report

December 2023

Snowy plover nest (photo credit: Stephanie Coates, Point Blue)
Cover photo: roosting snowy plover (photo credit: George Cummins, Point Blue)

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SUMMARY

The primary results of the 2023 breeding season are the following:

- The corrected window survey estimated that 314 western snowy plovers (*Charadrius nivosus nivosus*) nested in the Monterey Bay area in 2023.
- We documented 337 nesting attempts (297 active nests, 7 nests found when already inactive, and 33 broods of chicks from undetected nests).
- The apparent nest survival, or clutch hatch rate, was 62%.
- The nest survival estimated from the nest daily survival rate was 53%.
- A minimum of 502 chicks hatched.
- 320 chicks were banded and 127 (40%) of those survived to fledging age.
- An additional 112 unbanded chicks were confirmed to have fledged for a minimum number of 239 fledglings.
- The minimum estimate of chicks fledged per male was 1.44, which is above the 1.0 target needed for population stability.
- Breeding efficiency (BE) was greater than 0.2 (0.26), reiterating that there were likely more than 1.0 fledglings per male overall.
- 54% of all nest failures were attributed to predators.
- Of nest failure caused by predators, 27% was attributed to avian predators, 48% to mammalian predators, and 25% to unknown predators.
- Nest failures attributed to avian predators were almost entirely to species from the Corvidae family (corvids), but half of those failures occurred over a two-day window at one site (Zmudowski).
- The majority of nest failures attributed to mammals were either skunks (family Mephitidae) or species from the Canidae family (canids). More nest failures were attributed to them than to corvids.
- Nest success and fledge rates were higher in the South Bay than the North Bay. Also, a greater proportion of nest failures with a known cause were attributed to predators in the South Bay.
- At least one nest has been recorded at Laguna Creek beach in four of the past six years, including one nest in 2023. Monitoring effort has been lower here, so three nests had unknown fates, but two others were confirmed to have hatched.

INTRODUCTION AND BACKGROUND

The Pacific Coast population of the western snowy plover (*Charadrius nivosus nivosus*) was listed as threatened by the U.S. Fish and Wildlife Service (USFWS) in 1993. Point Blue Conservation Science (Point Blue) in partnership with USFWS, the California Department of Parks and Recreation (California State Parks) and other partners, has monitored nesting western snowy plovers (hereafter snowy plover or plover) in the Monterey Bay region since 1984. Beginning in the mid-1990s, this multi-agency working group has collaboratively planned, implemented, and assessed the effects of management actions taken to protect nesting plovers and meet the population target of 338 breeding plovers and the annual productivity target of 1.0 chicks fledged per breeding male identified in the federal Recovery Plan (USFWS 2007). Here we report on reproductive success and breeding population size of western snowy plovers in the Monterey Bay region in 2023 to assess the effect of management efforts intended to support population recovery.

METHODS

Study Area and Annual Monitoring Objectives

The study area includes the beaches of Monterey Bay and the former salt ponds within Moss Landing Wildlife Area adjacent to Elkhorn Slough, and beaches in northern Santa Cruz County. We monitored in two regions, the North and South Bay, divided at the Elkhorn Slough. The North and South regions are split into 14 major monitoring areas and include a total of 23 individual sites. For calculations in 2023, we included the salt ponds in the northern region. See Appendix A for area maps and Appendix B for a detailed description of each area.

In 2023, our specific monitoring objectives were to locate and protect nests, determine nest fate, and to band a sample of at least 50% of chicks that hatched to determine bay-wide and site-specific fledge rates where possible.

The methods we used for nest monitoring, banding, and conducting the range-wide window survey followed our standard monitoring protocol described in detail in Appendix C. All snowy plover monitoring by Point Blue Conservation Science staff was conducted under USFWS permit number ES-807078-20. Planned monitoring activities in 2024 are expected to be similar to those conducted in 2023 and in previous years.

Analytic Methods

Due to the high proportion (86%) of nests with one or more unidentified or unbanded breeders in 2023, we did not generate a population estimate based on nest monitoring. Instead, we generated the population estimate by applying a correction factor of 1.22 to the 2023 window survey estimate. The correction factor of 1.22 is based on the relationship between the window survey estimate and the number of individual breeding plovers identified on nests during the years 2000–2019 in the Monterey Bay region (see Appendix D for details on analytical methods and past protocols for determining breeding population size). We calculated the percentage of banded male and female plovers that were confirmed or probable breeders in 2022 which returned to breed in 2023. We also calculated the percentage of banded fledglings in 2022 which returned to breed in 2023. Details of the methods for calculating return rates of confirmed and probable breeders is in Appendix D.

For continuity with past reporting, we calculated apparent nest success (i.e., clutch hatch rate), which is the percent of nests that successfully hatched at least one chick. Because this rate doesn’t account for nests that failed before they were found, apparent nest success is usually an overestimate of the actual hatch rate. For more accurate estimates, we modeled nest daily survival rate (DSR) for nests that met modeling criteria using the RMark package within Program R (Laake 2013; R Core Team 2023). We also examined the effect of time, nest age, nesting density, and predator removals by location (region and bay-wide) on DSR. Detailed analysis methods for nest survival are included in Appendix D.

We compared the timing of nest hatches as well as timing of nest failures between the North and South Bay using density plots, which are smoothed histograms.

We calculated the fledge rate as the number of confirmed banded fledglings per total number of banded chicks. We estimated the error around the fledge rate for banded chicks based on Henkel et al. 2020. This estimate, the Error Estimate Bound, is based on the approximate proportion of broods that were monitored (i.e., the proportion of nests that were confirmed to have hatched in which we banded one or more chicks).

To compare overall productivity between individual sites, and as a secondary estimator of the annual productivity target of one fledgling per male, we calculated a breeding efficiency metric for Monterey Bay overall, for each site, and across the landscape on an individual nest basis. Breeding efficiency (BE) is a measure of overall productivity which represents the ratio of the number of fledglings to the number of eggs laid (Colwell et al. 2018). This metric has been found to be highly correlated with the number of fledglings per male, with a BE of 0.2 and higher equaling at least 1.0 fledglings per male (Colwell et al. 2018, Appendix D). BE is more easily calculated for individual sites than the number of fledglings per male since adult snowy plovers sometimes move to different sites between nesting attempts. Additionally, management actions are often conducted at a site-level scale. We calculated BE as the minimum number of fledglings divided by the minimum number of eggs laid.

Management

Management activities to improve snowy plover reproductive success were coordinated and implemented by a multi-agency working group that included Point Blue, California State Parks, USFWS, and other coastal land managers and owners. Activities in 2023 included outreach to beach users by plover researchers, predator control by the Wildlife Services Division of the U.S. Department of Agriculture (USDA), water management to provide nesting and foraging habitat in the managed former salt ponds of the CDFW's Moss Landing Wildlife Area, and ongoing protection and restoration of beach and dune habitats by landowners, managers, and partner organizations. Water management at Moss Landing Wildlife Area consists of opening tidal gates to allow water into pond storage areas and subsequently into shallow channels within nesting ponds. This water provides foraging habitat for plover chicks and other waterbirds during the drier summer months. Beach nesting habitat was protected using cable or rope fencing and regulatory/informational signs to temporarily (March 1st – Sept. 30th) restrict recreational access to nesting areas on upper beaches and dunes and the non-public portions of the salt ponds at Moss Landing Wildlife Area.

RESULTS

Monitoring and Management Activities

In 2023, we monitored for 1,496 total hours. Monitoring effort was not evenly distributed among sites; among the 14 major monitoring areas (Appendices A & B), three sites combined accounted for over 38% of all field effort (Sunset-Manresa, Zmudowski, and Salinas River NWR) while three different sites combined accounted for only 7% of all field effort (Sand City, Reservation Road, and Monterey), with sites ranging from <2% to almost 16% of all field effort individually (See Appendix E for details of the 2023 monitoring effort). In 2023, most nests were protected by temporary fencing or were within permanently closed areas (98%; 290 out of 297 nests found prior to hatch). No nest exclosures were used in 2023. USDA biologists conducted selective removal of avian and mammalian predators in

2023 as guided by the multi-agency working group. A pair of northern harriers (*Circus hudsonius*) nested in the back dunes of Salinas River NWR, and, after the nest was located, the eggs were oiled to prevent the eggs from hatching, and the harriers from potentially using plovers as a food source for their chicks. Water management at the salt ponds to create dry nesting substrate and wet foraging areas for plovers was conducted by CDFW staff. The type of recreational uses allowed at each site, the level of recreation, and enforcement of regulations on recreational use vary by site and by landowner or manager.

During the 2023 nesting season, pursuant to our permit, the Arcata Fish and Wildlife Office of USFWS granted approval of removal of six eggs from two clutches; in both clutches the eggs were infertile and were being incubated by the pair well beyond the incubation period (more than 2 weeks beyond the expected hatch date). USFWS also granted permission for a single female adult to be captured and placed at the Monterey Bay Aquarium as an ambassador bird. This female was banded and had been documented to lay infertile eggs for at least three breeding seasons in a row.

Breeding Population Size and Return Rates

On the annual range wide breeding window survey, we estimated a breeding population of 257 adults (142 males, 99 females and 16 unknown sex; Figure 1). We applied a 1.22 correction factor to the 2023 window survey estimate to generate a corrected breeding population estimate of approximately 314 plovers.

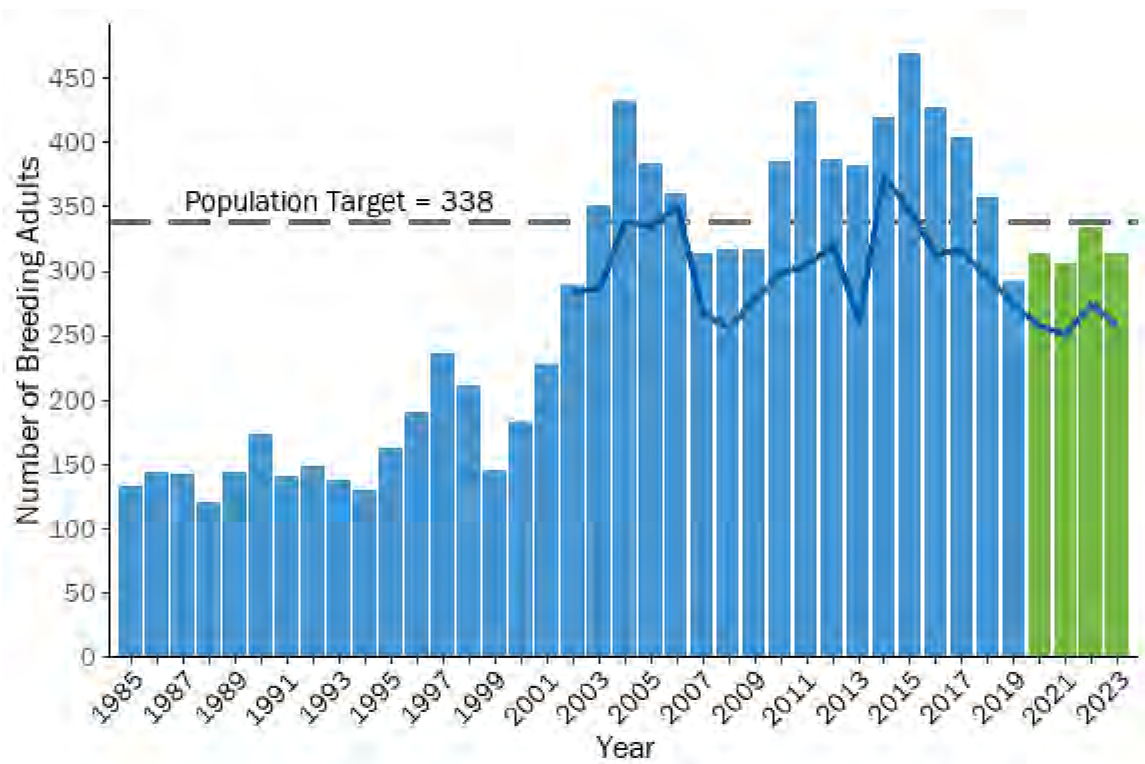

Figure 1: *Number of breeding snowy plovers from monitoring (bars) and window surveys (line) in the Monterey Bay region, 1985–2023. Beginning in 2020, the number of breeding snowy plovers from monitoring were calculated by applying a correction factor of 1.22 to window survey totals (green bars).*

Of color-banded adults that were confirmed or probable breeders in the Monterey Bay region in 2022, 71% of 78 males and 54% of 67 females returned and bred or were suspected of breeding in 2023. Although the male return rate was on par with the average rate of 70% for males from 2012–2022, the female return rate was much lower in 2023 (average rate of 66% from 2012–2022). An additional three females that were confirmed or probable breeders in 2022 were observed on Monterey Bay between May and June but had insufficient evidence to be considered a confirmed or probable breeder in 2023.

Of 77 banded fledglings from 2022, 38% returned to breed on Monterey Bay in 2023. This is slightly more than the proportion of banded fledglings from 2020 and 2021 that returned to breed in the following year (33%).

Nesting Attempts and Phenology

In 2023, we documented 337 nesting attempts (297 active nests, 7 nests found when already inactive, and 33 broods of chicks from undetected nests), and we determined the fate of 96% of the nests found at the egg stage (Table 1, see Appendix A for maps). In 2023, nesting occurred at all major sites where nesting was documented in 2022. Additionally, a nest was found on Laguna Creek beach and successfully hatched. Although there was a gap with no recorded nests at Laguna Creek between 2004 and 2018, there has been at least one confirmed nest there in four of the past six years. The first nest was initiated on March 24 at Reservation Road and the last nest on July 13 at Salt Ponds, with a median clutch initiation date of May 13. Nesting commenced slightly earlier in the South Bay (Molera-Potrero south through Monterey) than in the North Bay (Northern Santa Cruz south through the Salt Ponds); the median clutch initiation date of South Bay nests (May 11) was earlier than the bay-wide median and 3 days earlier than for North Bay nests (May 14). The first nest was initiated on March 27 (Moss Landing) in the North Bay area and on March 24 (Reservation Road) in the South Bay area. The earliest fledging occurred on May 27 (Fort Ord and Salinas River NWR).

Snowy plover nest Photo credit: George Cummins, Point Blue

Table 1: Apparent nest success of snowy plovers across sites in the Monterey Bay region in 2023.

Location[1]	Total Nesting Attempts (n)[2]	Found as Broods (n)	Found as Nests (n)	Known Fate Nests (n)[3]	Hatched Nests (n)[3]	Apparent Nest Success[4,5]
Laguna Creek	1	0	1	1	1	100%
Sunset-Manresa	26	5	21	21	9	43%
Pajaro	20	2	18	18	11	61%
Zmudowski	47	1	46	45	26	58%
Moss Landing	21	0	20	20	8	40%
Salt Ponds	19	5	14	12	8	67%
Molera-Potrero	10	0	10	10	6	60%
Monterey Dunes	18	5	11	11	10	91%
North Salinas River	20	2	18	18	16	89%
Salinas River NWR	40	0	39	37	31	84%
Marina Dunes	45	4	41	40	21	52%
Reservation Road	18	1	15	14	8	57%
Fort Ord	31	3	27	24	16	67%
Sand City	8	4	4	3	0	0%
Monterey	13	1	12	11	5	45%
GRAND TOTAL	**337**	**33**	**297**	**285**	**176**	**62%**

[1]Locations are listed geographically from north to south
[2]Sum of nests found at the egg stage and the brood stage, including those found already inactive
[3]Nests found as broods are not included
[4]The number of hatched nests divided by the number of known fate nests
[5]Nests found as broods and unknown fate nests not included

Nesting Success and Fledge Rates

Apparent Nest Success

Of the 285 known fate nests found at the egg stage, 176 hatched, for an apparent nest success of 62% (see Table 1). Overall, since 2000 apparent nest success has declined (Kendall rank correlation coefficient $\tau = -0.56$, $p < 0.001$). However, despite this overall decline in apparent nest success, it has been increasing for the past five years (Figure 2). Apparent nest success in the North Bay was lower than in the South Bay (54% versus 67%;

Table 2). These nest success rates should be considered maximums both because we suspect that some nests were depredated before we were able to locate them and because most nests classified as unknown fate probably did not hatch.

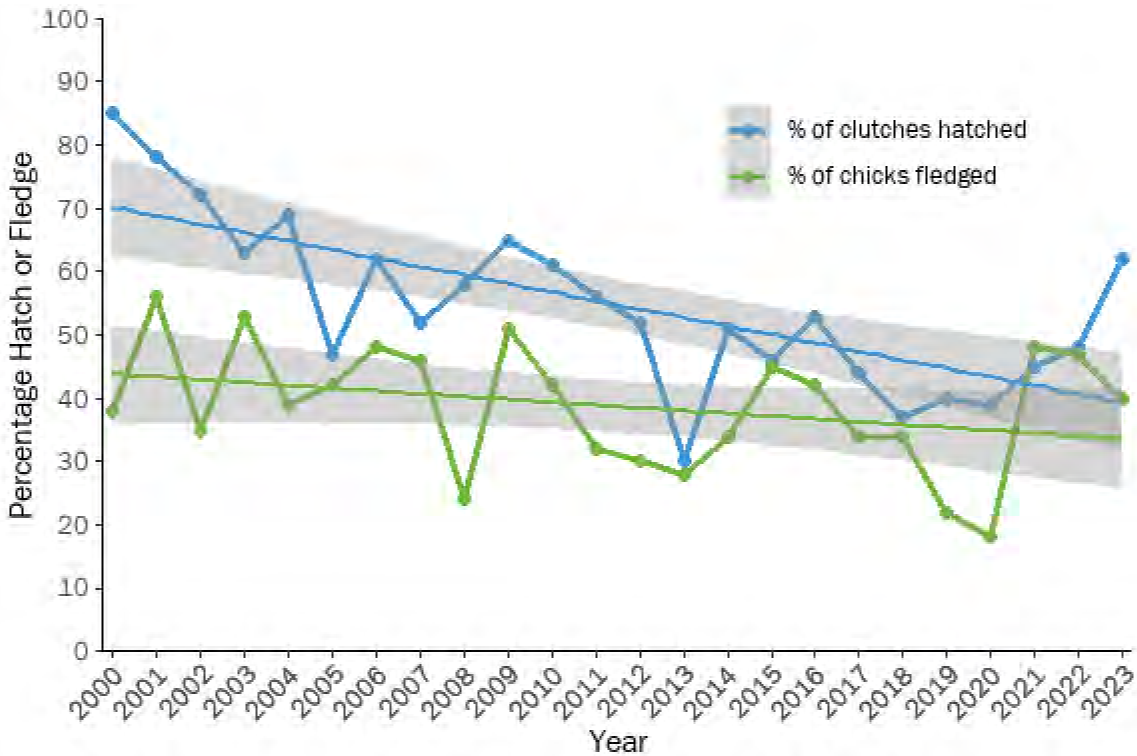

Figure 2: *Percentage of clutches that hatched (apparent nest success) and chicks that fledged in the Monterey Bay region, 2000–2023. Clutches that hatched one or more eggs were considered hatched. Chicks were considered fledged if they survived to 28 days old. The 95% confidence interval is shown as the shaded gray band around each linear regression trend line.*

Table 2: Apparent nest success of snowy plovers across regions of Monterey Bay in 2023.

Location[1]	Total Nesting Attempts (n)[2]	Found as Broods (n)	Found as Nests (n)	Known Fate Nests (n)[3]	Hatched Nests (n)[3]	Apparent Nest Success[4,5]
North Bay	134	13	120	117	63	54%
South Bay	203	20	177	168	113	67%
GRAND TOTAL	**337**	**33**	**297**	**285**	**176**	**62%**

[1]North locations are sites from Elkhorn Slough northward, while South locations are sites south of Elkhorn Slough
[2]Sum of nests found at the egg stage and the brood stage, including those found already inactive
[3]Nests found as broods are not included
[4]The number of hatched nests divided by the number of known fate nests
[5]Nests found as broods and unknown fate nests not included

Nest Daily Survival Rate

Supplementing apparent nest success with DSR modeling, we estimated an overall nest survival rate of 53% (95% CI 46–59%) calculated over a 32-day nesting period (Table 3). Of 337 total nests in 2023, we removed 12 nests with unknown fate, 33 nests that were found as broods after hatching, 8 nests that were found after the nest was inactive or were monitored for 0 days (e.g., 1 egg found, never attended while monitored), and 1 nest that was at Laguna Creek, leaving a sample of 283 nests that met modeling criteria. As expected, DSR modeling produced lower survival estimates than apparent nest success (see Tables 1 & 2).

We modeled DSR using covariates for time, nest age, nest density at multiple scales, pressure and protection from predators, and categorical groupings of geographic region. We found that DSR was best described by an interactive effect of region (North Bay and South Bay) and the number of simultaneously active nests in a 500m radius (Figure 3). In the North Bay, the relationship between nest density and nest survival was relatively linear, with survival and nest density positively correlated. In the South Bay, nest survival increased with nest density until reaching approximately 13–15 nests within 500m, after which survival asymptotically approached 100%. Estimated nest survival from DSR modeling also followed a similar geographical pattern to that of apparent nest success; the 61% survival estimate for the South Bay (95% CI 52–68%) is approximately 20% higher than the 40% estimate for the North Bay (95% CI 30–50%; Table 3). We first included nest age in our predictive model sets to examine effects over the nesting period. Not including nest age can bias results, especially if nests are found later in the nesting period or the age at which nests are found differs between comparison areas (Weiser 2021). However, median nest age when found was relatively young (8 days), the age when found did not vary significantly between North and South Bay regions ($t = 0.601$; North Bay $\bar{x} = 8.73$, South Bay $\bar{x} = 8.28$), and nest age was not a strong predictor in modeled results. Therefore, we did not include it in final models for DSR estimates by location.

To better examine the effect of predator management, we developed and incorporated a “Protection Factor” covariate into the DSR models. A higher Protection Factor equated to a higher level of predator management and was assessed for each nest in various iterations. We evaluated estimates for avian predators (ravens and crows) based on predator removal data provided by USDA. Of 61 total individual crows or ravens removed, 55 of the removals occurred before the median clutch initiation date of May 13th (median = May 3rd; min = April 1st; max = June 15th). DSR models that included any variety of Protection Factor metrics we incorporated were not highly ranked in our candidate set. We also included covariates for predator pressure, with the hypothesis that the number of predators at a site may offset the protective effect afforded by predator removals. We used the maximum counts of ravens and crows at the site in which a nest was located, during the window of time between the clutch initiation date of a nest and 32 days after clutch initiation. Like the Protection Factor, these were not strong predictors and not included in final DSR models.

Table 3: Estimated Daily Survival Rate (DSR), nest survival percentages, and 95% confidence intervals for the two major geographic regions in the Monterey Bay region in 2023. Estimates are from a constant daily survival rate model that included region as a covariate. Salt Ponds nests (n = 12) are grouped with the North Bay.

Location[1]	Nests in Analysis (n)[2]	Est. DSR	DSR 95% CI lower	DSR 95% CI upper	Est. Nest Survival (%)[3]	95% CI lower (%)[3]	95% CI upper (%)[3]
North Bay	115	0.972	0.963	0.979	40	30	50
South Bay	168	0.985	0.980	0.988	61	52	68
Overall	**283**	**0.980**	**0.976**	**0.984**	**53**	**46**	**59**

[1]North locations are sites from Elkhorn Slough northward, while South locations are sites south of Elkhorn Slough

[2]Number of nests which met modeling criteria. Nests found in the brood stage, with unknown fate, with zero monitoring days, or outside of the Monterey Bay area (e.g., Laguna Creek) are not included.

[3]Daily Survival Rate exponentiated by a median nesting period of 32 days.

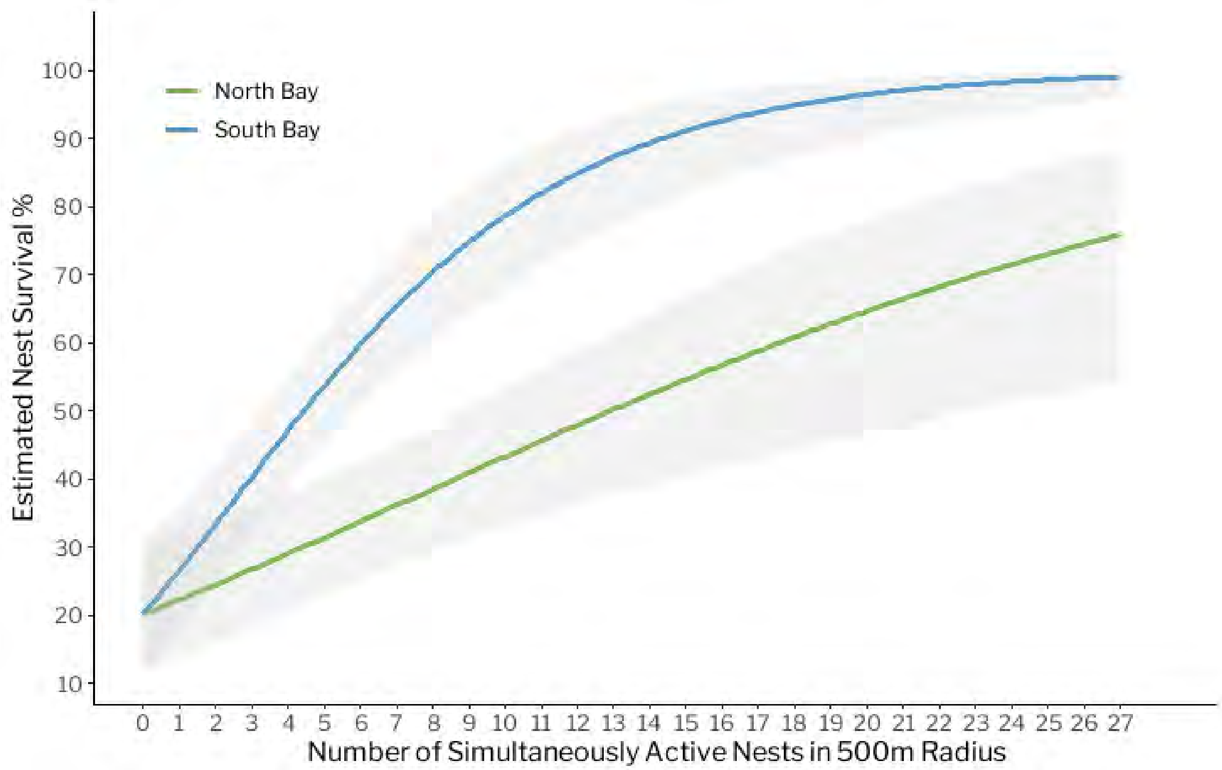

Figure 3: *Estimated nest survival and 95% confidence intervals (in shaded grey) in the North and South Bay regions of Monterey Bay in 2022 for 283 nests that met model criteria. Estimates are from a daily survival rate model that included the interaction of region and the density of simultaneously active nests (number in 500m radius) as covariates. Daily survival rates were exponentiated by a median nesting period of 32 days to produce estimated nest survival percentages.*

Fledge Rate

We confirmed that a minimum of 502 chicks hatched from 337 nesting attempts (Table 4, see Table 1). An additional 95 chicks may have hatched from the sum of nests where fate was unknown (12 nests) and from nesting attempts where some, but not all eggs in the clutch were confirmed to have hatched (176 hatched nests and 33 broods of chicks from undetected nests; see Table 1).

We banded a sample of 320 chicks (64% of the minimum number of chicks that hatched; Table 4) from 133 of the 176 nests that hatched (76%). Of the banded sample, 40% (127 banded fledglings) survived to fledging age (Table 4). Monitoring 76% of broods yielded an Error Estimate Bound (Henkel et al. 2020) of approximately 9% of the fledge rate, resulting in an error around the fledge rate of ± 4.5%, or an overall fledge rate estimated from banding of 35.5–44.5%. Because the Error Estimate Bound relies on determining the proportion of nests that hatched, it may have been slightly biased by our failure to detect chicks hatching at nests that were categorized as unknown fate (12 nests), but we suspect that it is more likely that most of these unknown fate nests failed. Overall, since 2000 the bay-wide fledge rate has had no significant trend upwards or downwards (Kendall rank correlation coefficient $\tau = -0.21$, $p = 0.16$). However, the past three years have had fledge rates well above the trend line (see Figure 2).

Fledge rates across areas were highly variable (Table 4); the total number of chicks banded at some sites was low and thus fledge rates should be interpreted in this context. In addition to the 127 banded fledglings, we confirmed an additional minimum number of 112 unbanded chicks that reached fledge age for a total minimum number of 239 fledglings (Table 4). The North Bay had a banded fledge rate (31%) a little more than two-thirds that of the South Bay (44%; Table 5). This was largely driven by the low fledge rate at Zmudowski and Moss Landing, both of which had fledge rates markedly lower than the bay-wide and regional (North and South Bay) averages.

Snowy plovers hatching. Photo credit: George Cummins, Point Blue

Table 4: Number of chicks hatched and fledging success of unbanded (UB) and banded snowy plover chicks in the Monterey Bay area in 2023.

Location[1]	Min Chicks Hatching (n)	Max Chicks Hatching (n)[2]	Min UB Chicks Fledging (n)[3]	Max UB Chicks Fledging (n)[4]	Banded Chicks (n)	Banded Chicks Fledging	Banded Fledge Rate
Laguna Creek	3	3	0	3	0	0	--
Sunset-Manresa	33	40	12	13	15	7	47%
Pajaro	32	36	5	5	26	10	38%
Zmudowski	64	73	4	15	47	10	21%
Moss Landing	18	20	1	1	15	4	27%
Salt Ponds	29	40	21	27	2	2	100%
Molera-Potrero	11	13	2	2	7	4	57%
Monterey Dunes	34	41	11	15	19	6	32%
North Salinas River	44	49	5	10	33	14	42%
Salinas River NWR	74	85	7	15	58	29	50%
Marina Dunes	61	72	26	34	30	18	60%
Reservation Road	24	27	3	4	16	6	38%
Fort Ord	49	63	3	4	44	14	32%
Sand City	10	15	6	10	0	0	--
Monterey	16	20	6	7	8	3	38%
GRAND TOTAL	**502**	**597**	**112**	**165**	**320**	**127**	**40%**

[1]Locations are listed geographically from north to south
[2]Includes all possible hatching eggs from both known and unknown fate nests and from nests found as nests and broods
[3]Includes only chicks that were seen at fledging age (28 days) or older
[4]Includes all chicks that were seen alive during the brood rearing period

Table 5: Number of chicks hatched and fledging success of unbanded (UB) and banded snowy plover chicks across regions in the Monterey Bay area in 2023.

Location[1]	Min Chicks Hatching (n)	Max Chicks Hatching (n)[2]	Min UB Chicks Fledging (n)[3]	Max UB Chicks Fledging (n)[4]	Banded Chicks (n)	Banded Chicks Fledging	Banded Fledge Rate
North Bay	179	212	43	64	105	33	31%
South Bay	323	385	69	101	215	94	44%
GRAND TOTAL	**502**	**597**	**112**	**165**	**320**	**127**	**40%**

[1]North Bay locations are sites from Elkhorn Slough northward, while South Bay locations are sites south of Elkhorn Slough
[2]Includes all possible hatching eggs from both known and unknown fate nests and from nests found as nests and broods
[3]Includes only chicks that were seen at fledging age (28 days) or older
[4]Includes all chicks that were seen alive during the brood rearing period

Fledglings per Male

The minimum estimate of chicks fledged per male was 1.44, higher than the 1.0 target needed for population stability (USFWS 2007). This rate was calculated as the sum of the number of banded fledglings (127) and the minimum number of unbanded fledglings (112) (sum=239), divided by the approximate number of males (n=166, or 53% of the corrected window survey total of 314; 0.53 operational sex ratio based on Stenzel et al. 2011) estimated from the window survey method.

Breeding Efficiency

BE, which is highly correlated with the number of fledglings per male, showed similar results as our estimated number of chicks fledged per male in 2023. The overall BE across the Monterey Bay region in 2023 was greater than 0.2 (overall BE of 0.26), indicating there were likely greater than 1.0 fledglings produced per male in 2023 (1.44 fledglings per male was calculated; see Fledglings per Male above). When combined, the sites of all land managers had a BE of at least 0.2 (Figure 4). However, seven individual sites had a BE less than 0.2, indicating less than 1.0 fledglings produced per male in those areas in 2023 (Figure 5). Two of these sites were very close to a BE of 0.2 and likely did have 1.0 fledglings per male. Additionally, two of these seven sites had only one nest found, and although we couldn't confirm any fledglings at Laguna Creek, it is likely at least one chick fledged there based on the age of the chicks at the last check. Of the remaining three sites that were below a BE of 0.2, two of them are located in the North Bay, corroborating the lower productivity in the North Bay versus the South Bay observed in the nest success and fledge rate metrics. When BE is considered geographically, a pattern of higher BE in the central areas of the bay with lower BE in the north and south ends becomes apparent (Figure 6). Comparisons between Salt Ponds (CDFW and SP in Figures 4 and 5, respectively) and other sites should be interpreted with caution, as it's possible the detectability of fledglings or eggs (i.e., nests) differs in comparison with the rest of the monitoring area.

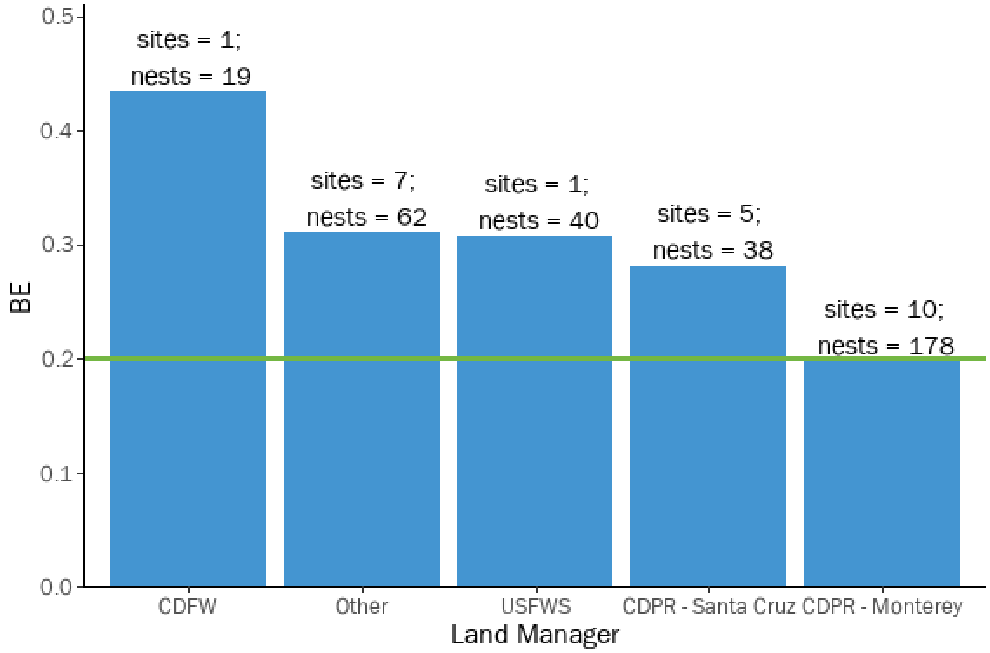

Figure 4: *Breeding efficiency (BE) across all land managers in the Monterey Bay region in 2023. The green horizontal line indicates a BE of 0.2 which correlates to at least ~1 fledgling per male. The number of individual sites within each land manager's jurisdiction as well as the number of known fate nests monitored are listed above each bar. See Appendix B for individual sites under each land manager's jurisdiction.*

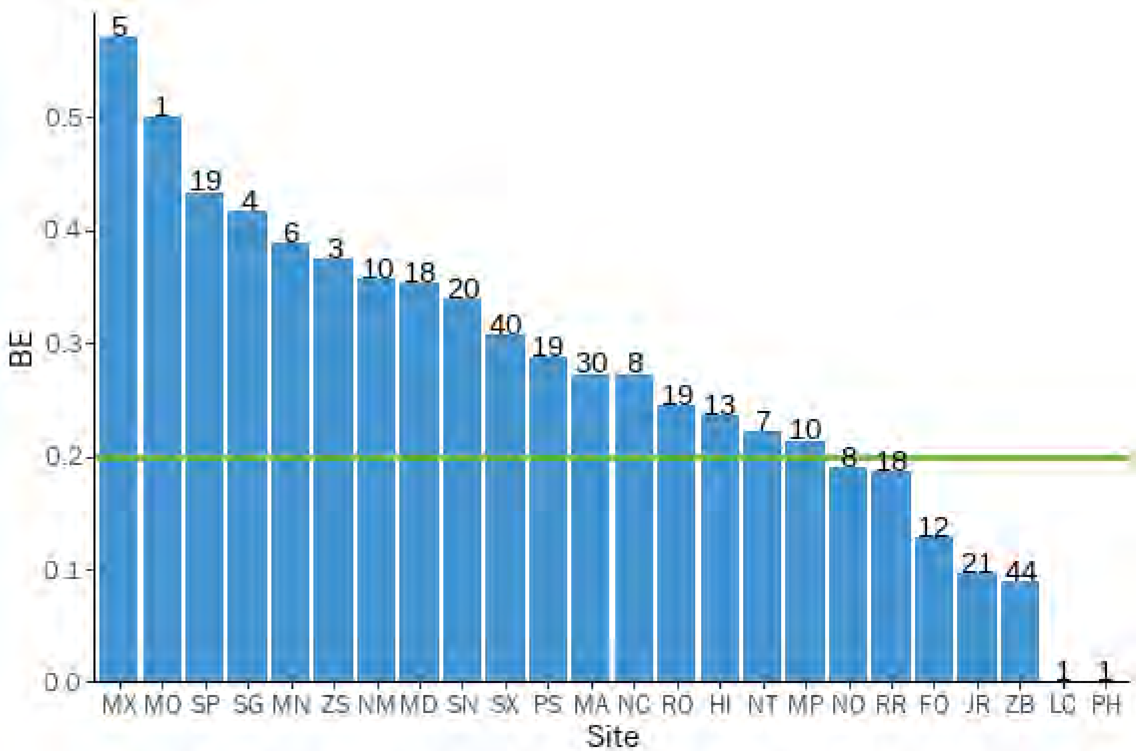

Figure 5: *Breeding efficiency (BE) across all sites in the Monterey Bay region in 2023. The green horizontal line indicates a BE of 0.2 which correlates to at least ~1 fledgling per male. The number of known fate nests monitored within each site is listed above each bar. See Appendix B for site name codes.*

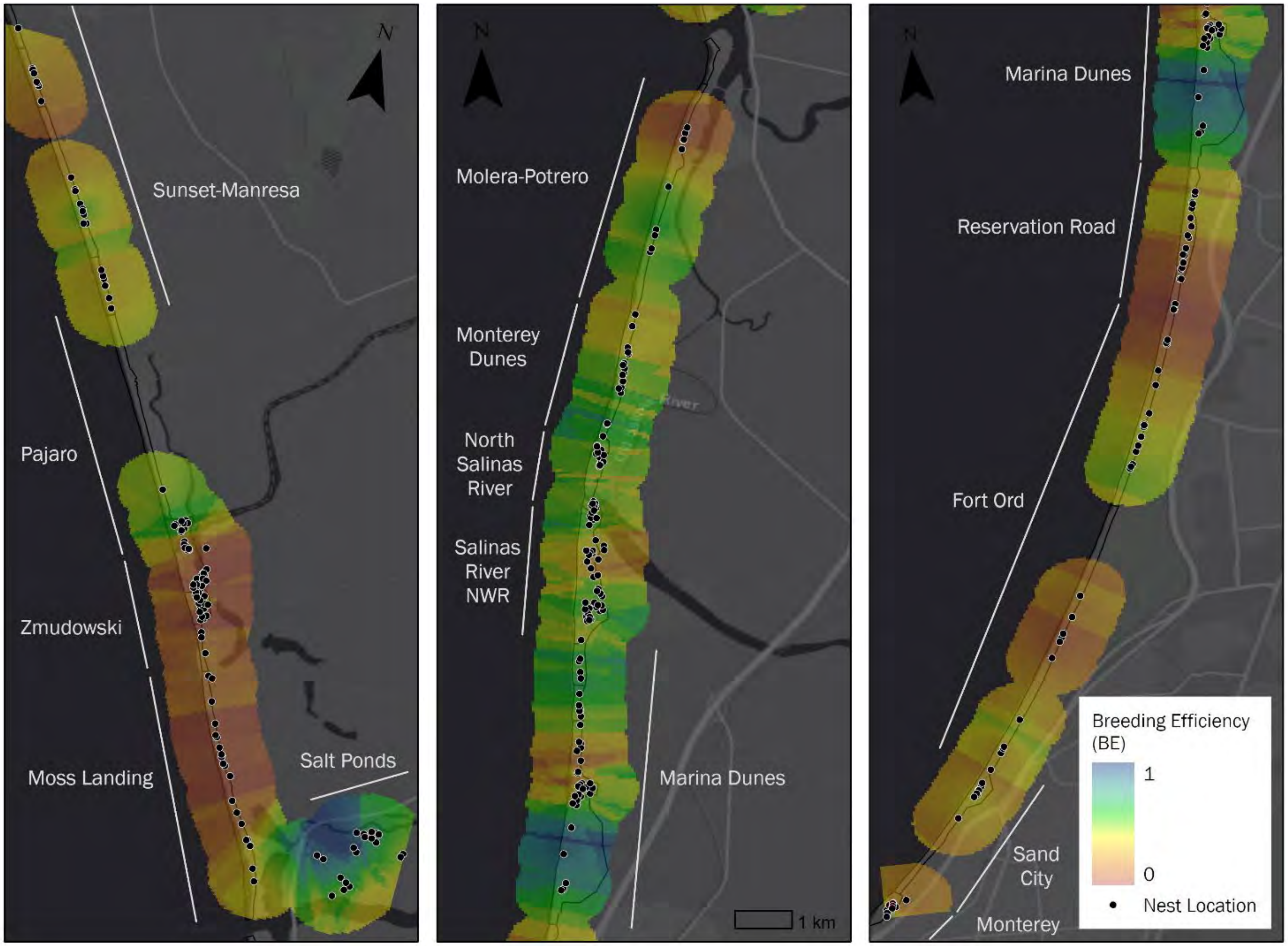

Figure 6: *Breeding efficiency (BE) calculated on a per-nest basis and mapped across the Monterey Bay region from the north (left) to the south (right) in 2023. BE is the minimum number of fledglings divided by the minimum number of eggs. Here, BE values at nests have been interpolated across the landscape with kriging in ArcGIS Pro (Esri 2022). Areas with green or blue tones have a higher BE than those with yellow or red tones.*

Causes of Nest Failure

Of 116 nests that failed in 2023, 54% of failures (63 failed nests) were attributed to predators (Table 6). Of the failures attributed to predators, 27% were attributed to avian predators, 48% to mammalian predators, and 25% to unknown predators. Predation by species within the family Corvidae (corvids) accounted for 24% of nest failure attributed to predators and was concentrated at Zmudowski. Common raven (*Corvus corax*) was the primary corvid that caused nest failure; all but one corvid-caused nest loss was directly (i.e., observed or with track evidence) or indirectly (i.e., raven event, see Appendix C) attributed to common raven (Table 6), with the remaining nest lost to American crow (*Corvus brachyrhynchos*). Only one non-corvid avian predator (gull, *Larus spp.*) was determined to cause a nest failure. Of failures attributed to mammalian predators (30 nests), 27% were caused by species within the family Mephitidae (skunks) and 27% were caused by species within the family Canidae (canids, including domestic dog, *Canis familiaris,* and coyote, *C. latrans*), affecting only sites in the South Bay (Table 6). Only one other mammal species was attributed with causing a nest failure – raccoon (*Procyon lotor*) in the North Bay (Table 6).

Nest abandonment occurred at seven nests (6% of failed nests), without an apparent spatial or temporal pattern (six different sites, within three different months). In an additional two instances, the entire clutch was found to be non-viable and removed by researchers.

Environmental factors (tide and wind) caused 6% of total nest failure. Tide (and tide event, see Appendix C) accounted for six out of the seven environmental losses.

Human-caused failure was the other identified cause of loss in 2023, occurring at five nests in separate areas: Sunset-Manresa, Zmudowski, Monterey Dunes, Marina Dunes, and Fort Ord (Table 6). At Sunset State Beach, a nest failed in the protective fencing due to human activity and the building of a driftwood 'fort' on the nest cup (no eggs were found, but the area was thoroughly disturbed). At Zmudowski, a nest failed most likely to human trampling – beach cart tracks went directly over the nest cup which was in the foredunes inside the protective fencing (eggshell fragments were found in the nest cup area). At Marina Dunes, a nest most likely failed because of human causes –many human tracks were found going through the nest cup area within the protective fencing. At Fort Ord, bicycle tire tracks were found going straight through a nest cup containing eggshell fragments and yolk cake.

Additionally, we collected eggs at one nest from Monterey Dunes to be raised in captivity after finding a dead adult within 7 inches of the nest cup. The two eggs were taken to the Monterey SPCA and found to be still alive. Only one chick hatched, and it was later euthanized after developing a leg fracture prior to being released. Necropsy results for both the adult and the chick are pending.

Nest failures due to unknown causes were widespread throughout the study area, although the proportion of failed nests with an unknown cause was twice as high in the North Bay (Table 6). Frequent high tide and high wind events confounded the ability to attribute cause of loss due to erasure of possible evidence, including tracks and egg remains. In total, we were unable to determine the cause of failure for 28% of nests (Table 6).

Table 6: Causes of failure for known fate snowy plover nests in the Monterey Bay region in 2023.

Location[1]	Avian Predators					Mammalian Predators						Unk. Pred. Spp.[5]	Environmental			Other			Unk. Cause	Total
	CORA[2]	CORA Event[3]	AMCR[4]	Gull	Unk. Avian	Dog	Coyote	Canine	Skunk	Raccoon	Unk. Mammal		Tide	Tide Event[3]	Wind	Aband.[6]	Viabil.[7]	Human		
Sunset-Manresa	1	0	0	0	0	0	0	0	0	0	3	0	0	1	0	1	1	1	4	**12**
Pajaro	1	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	4	**7**
Zmudowski	5	2	0	1	0	0	0	0	0	1	0	4	0	1	0	0	0	1	4	**19**
Moss Landing	0	0	0	0	1	0	0	0	0	0	0	2	0	1	1	2	0	0	6	**13**
Salt Ponds	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	3	**4**
NORTH BAY TOTAL	**7**	**2**	**0**	**1**	**1**	**0**	**0**	**0**	**0**	**1**	**3**	**8**	**0**	**4**	**1**	**3**	**1**	**2**	**21**	**55**
Molera-Potrero	0	0	0	0	0	0	0	0	0	0	0	3	1	0	0	0	0	0	0	**4**
Monterey Dunes	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	**3**
North Salinas River	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	**2**
Salinas River NWR	1	0	0	0	0	0	3	0	0	0	0	1	0	0	0	0	0	0	2	**7**
Marina Dunes	1	2	0	0	0	0	1	0	8	0	3	0	0	0	0	1	0	1	2	**19**
Reservation Road	0	0	0	0	0	2	0	1	0	0	0	1	1	0	0	1	0	0	2	**8**
Fort Ord	1	0	0	0	0	0	0	1	0	0	4	0	0	0	0	0	1	1	1	**9**
Sand City	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	2	**3**
Monterey	0	0	1	0	0	0	0	0	0	0	2	0	0	0	0	1	0	0	2	**6**
SOUTH BAY TOTAL	**3**	**2**	**1**	**0**	**0**	**2**	**4**	**2**	**8**	**0**	**10**	**8**	**2**	**0**	**0**	**4**	**1**	**3**	**11**	**61**
GRAND TOTAL	**10**	**4**	**1**	**1**	**1**	**2**	**4**	**2**	**8**	**1**	**13**	**16**	**2**	**4**	**1**	**7**	**2**	**5**	**32**	**116**

[1]Locations are listed geographically from north to south

[2]Common raven

[3]See Appendix C for definition of losses caused by predator and environmental events

[4]American crow

[5]Unknown predator species

[6]Abandonded; includes nests deserted after partial loss of clutch

[7]Eggs were not viable despite continued incubation by adults

Differences between North and South Regions of Monterey Bay

Differences in cause of nest failure between the North Bay and South Bay were most pronounced for mammalian predation and unknown caused losses. All nest failures that we attributed to canids and skunks occurred in the South Bay, while the single nest loss attributed to raccoon occurred in the North Bay (see Table 6). Our ability to attribute a cause of nest failure differed between the two regions. The North Bay generally has finer sand particles which are more easily transported by the wind, erasing evidence for the cause of nest failure. This erasure of evidence is reflected in the 38% of North Bay nest failures for which we were unable to attribute a cause. Comparatively, the South Bay had approximately half that with only 18% of failures assigned to an unknown cause (see Table 6).

We found that the timing of predator-caused nest failure and successful nest hatching differed by region (Figure 7). Most predator-caused failures in the North Bay occurred early in the breeding season, whereas in the South Bay they occurred mostly in the mid and late season. Both regions experienced higher nest failure due to unknown and other causes earlier in the season (Figure 7). The proportion of hatching nests over time varied inversely with all causes of failure in the North Bay. In the South Bay, the signal was more mixed, with the peak in hatching occurring after the early season peak in nest failure due to unknown and other causes, but before the mid-season peak of nests failing to predators (Figure 7). Hatching peaked earlier and tapered off throughout the season in the South Bay, while it continued rising until very late in the season in the North Bay (Figure 7).

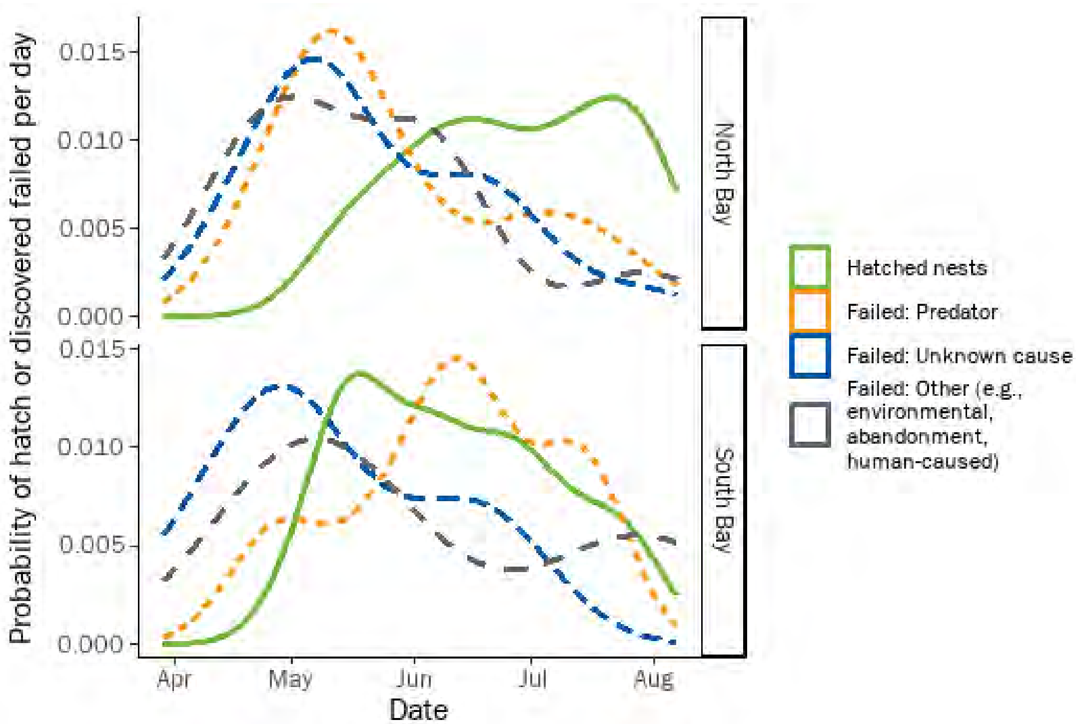

Figure 7: Proportion of nest hatches and nest losses attributed to predators, unknown causes, and grouped other causes of loss (such as abandonment or loss to environmental or human causes) over time in the North and South Bay regions in 2023. Each line is the smoothed distribution of the count of occurrences at a point in time, standardized by the total count of occurrences for that category (e.g., number of nests that hatched at a given date divided by total number of nests that hatched across all dates).

Captive Rehabilitation and Injuries

During the 2023 breeding season, eggs or chicks from five separate nests were collected to be raised in captivity. On May 3rd, a nest at Reservation Road (RR03) was found tide-washed and all three eggs were taken to the Society for the Prevention of Cruelty to Animals for Monterey County (SPCA) in Salinas, CA where it was found that none of them were still viable. On May 10th a nest at Molera-Potrero (MP04) was found tide-washed, with one egg broken and the other approximately two meters from the original nest cup. The unbroken egg was taken to the SPCA where it was found to be still alive but died later that night. Also on May 10th, a nest at North Salinas River (SN01) was deemed abandoned after checking it for three days upon which all three eggs were taken to the SPCA. Two of these eggs were still alive but died without hatching a few days later. On July 22nd a banded chick was delivered to the SPCA by a member of the public, three days before its expected fledge date (MD11). This chick was later released on August 15th at the Salinas River NWR. One adult was found dead at a nest cup (MD13) on June 22nd. The carcass was intact with no plucked feathers although its eyes were already missing or sunken in. The bird was collected and delivered to the Marine Wildlife Veterinary Care and Research Center (MWVCRC) in Santa Cruz, CA where it was tested for highly pathogenic avian influenza (the result was negative) and kept for future necropsy. The nest had two eggs, both of which were collected and given to the SPCA. One of these eggs hatched, but prior to release the chick developed a fractured leg and an eye infection and was ultimately euthanized.

Releasing a captive-reared snowy plover. Photo credit: Yvonne Wright

One adult male snowy plover was found with an entanglement of its left foot at Sunset State Beach. The bird was trapped on April 5th and most of the filaments were removed before releasing the bird on-site. Only one left toe was still remaining, and it appeared that it would soon be lost, but the leg and color bands were unaffected. The plover had multiple nests at Sunset State Beach and visually looked mobile and healthy throughout the breeding season.

Human Activity

Human activity observed during plover surveys increased in 2023 after declining the previous two years. However, there is no overall significant increasing or decreasing trend for human activity since 2008 (Kendall rank correlation coefficient $\tau = 0.3$, $p = 0.12$; Figure 8). In 2023, human activity was the second lowest recorded since 2014. The rate of dog activity increased in 2023 compared with 2022 and was the second highest recorded since 2008. The overall trend is significantly increasing (Kendall rank correlation coefficient $\tau = 0.77$, $p < 0.001$; Figure 9). Rates of both on- and off-leash dogs are likewise significantly increasing (Kendall rank correlation coefficient $\tau = 0.78$ and 0.8, respectively, both $p < 0.001$), although only off-leash dogs are shown in Figure 9. This is particularly striking given that dogs are prohibited on more than 75% of the beaches within the area.

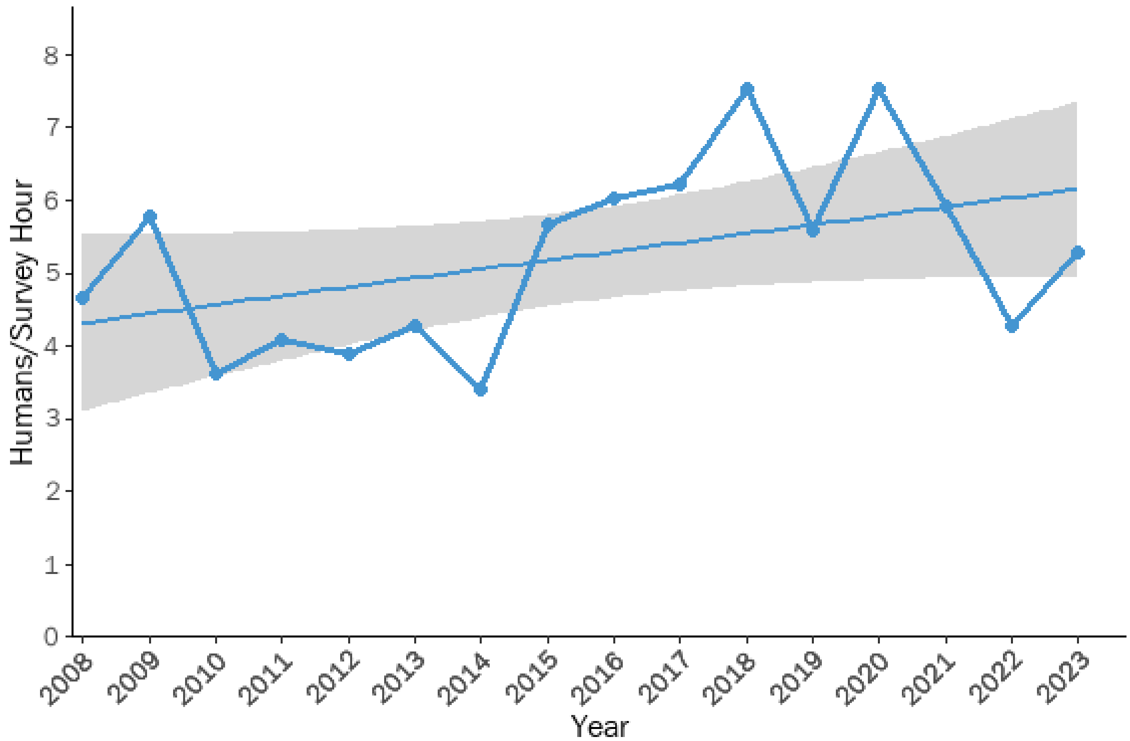

Figure 8: *Level of human activity (encounter rates of all human activities per survey hour) at snowy plover nesting beaches in the Monterey Bay region, 2008–2023. The 95% confidence interval is shown as the shaded gray band around a linear regression trend line.*

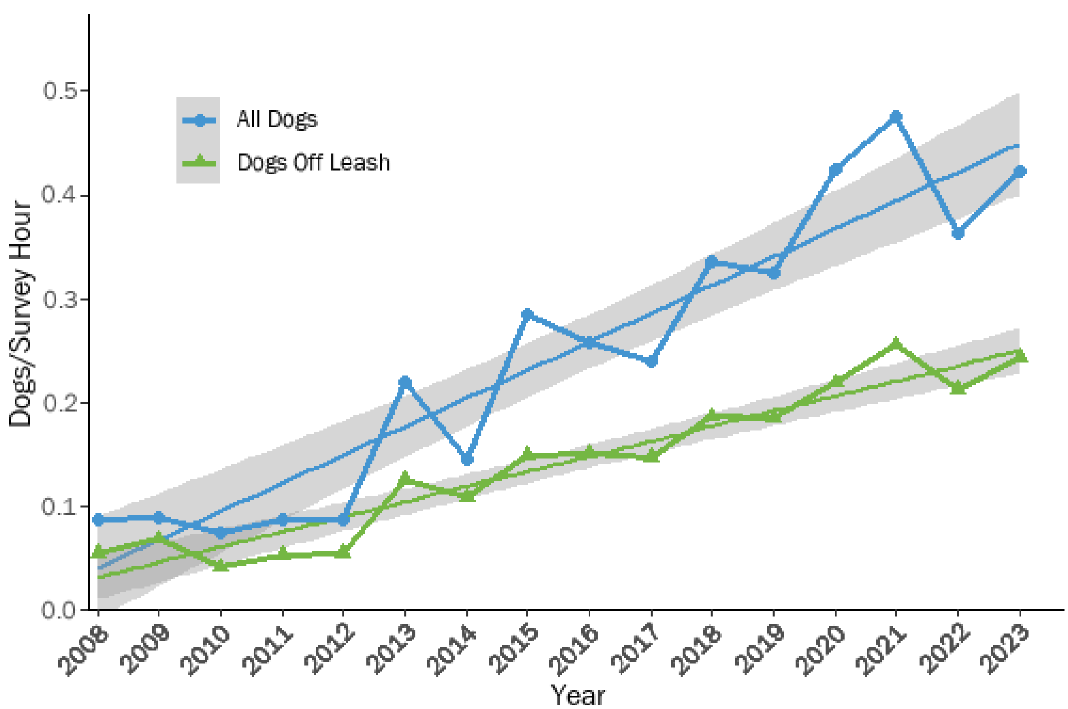

Figure 9: *Level of dog activity (encounter rates of all dogs and just dogs that were off-leash per survey hour) at snowy plover nesting beaches in the Monterey Bay region, 2008–2023. The 95% confidence interval is shown as the shaded gray bands around the linear regression trend lines.*

DISCUSSION

Our corrected window survey estimate of 314 breeding snowy plovers in the Monterey Bay region in 2023 did not meet the USFWS Recovery Plan target of 338 adults for the region for the fifth consecutive year and for the eighth time since the recovery target population was first reached in 2003. The Monterey Bay breeding population declined from 2022 to 2023, although overall it has been relatively stable over the past five years.

The 239 confirmed fledglings in 2023 was well above the benchmark of 169 fledglings needed to maintain the population at the recovery target of 338. The 2023 minimum number of chicks fledged per male (1.44) was also well above the recovery target of 1.0 chicks per male for population stability. The overall BE in 2023 also suggests that the target of 1.0 chicks per male was attained. However, on a site-by-site basis, BE indicates that some individual areas, especially in the North Bay and southern South Bay, were still underperforming in terms of breeding productivity.

The high number of fledglings and fledglings per male can be attributed to the high nest success in 2023. Although the fledge rate in 2023 was above the bay-wide trend line for fledge rate from 2000 through 2023, it was lower than the previous two years, whereas apparent nest success was the highest since 2009. This difference in hatching and fledging rate indicates that survival pressures during these two phases of the breeding cycle are not the same. However, determining causes of chick mortality continues to be challenging because mortality is rarely observed. Additionally, we do not have evidence as to why fledge rates in the South Bay are higher than those in the North Bay. Diurnal raptors are common at many sites (e.g., northern harrier at salt ponds and Salinas River NWR); however, in 2023, we have no direct evidence of avian predators depredating chicks.

Daily Survival Rate modeling indicated that nest survival was best estimated by an interactive effect of region and nest density as measured by the number of simultaneously active nests within a 500m radius. These models should be interpreted in a descriptive manner rather than as a causal effect – we cannot say that nest density is driving nest success. However, this scale may be important to plovers for other reasons – perhaps other habitat components that create quality nesting habitat occur on a similar scale and encourage nesting at a higher density. As the number of nests within a 500m radius (essentially a 1km stretch of coastline) best estimated nest survival out of the various spatial scales we included (from approximately 50m to 5,000m radii), it could be worth exploring what specific environmental components are meaningful to plovers at this scale.

While we do not have a definitive reason why nesting success was so much higher in 2023, one contributing factor could be an abundance of other food sources for nest predators. Anecdotally, we observed a high number of voles (*Microtus* spp.) at Salt Ponds which were not observed in the past couple of years. Additionally, a northern harrier was seen at the salt ponds on almost every visit to the site, yet both hatching and fledgling success appeared high. A pair of northern harriers nested in the back dunes of Salinas River NWR, but once again, there was no apparent predation by harriers in that area. Like the Salt Ponds, we anecdotally observed many prey species (e.g., brush rabbits, *Sylvilagus bachmani*), east of the back dunes at the Salinas River NWR. Possibly the wet winter of 2022–2023 resulted in an increase in small mammal populations to the degree that raptors and other snowy plover egg and chick predators were able to thrive on these other prey items during the 2023 breeding season.

Compared with the previous three years, proportionally more nest failures were attributed to predators than other causes of loss in 2023 (54% compared with 40%, 44%, and 44% in 2022, 2021, and 2020, respectively; Neuman et al. 2022, 2021a, 2021b). However, during the previous three years well over half of the nests that failed due to predators were attributed to avian predators, while that number was noticeably lower in 2023 (only 27% of predated nests were attributed to avian predators). Only once in 2023 were multiple nests depredated close in time and space due to corvids (e.g., raven event), while this happened many times at different sites in 2022. In fact, half of all nest failures that were attributed to corvids occurred at Zmudowski during a two-day period in the first part of May. This is potentially due to USDA removing many corvids from beaches early in the breeding season (i.e., in April). Alternatively, the low rate of nest failure to corvids in 2023 could be due to some outside factor such as an increase in other food availability or an increase in natural mortality due to highly pathogenic avian influenza. This reduction in the apparent threat posed by avian predators in 2023 may help explain why covariates related to avian predator pressure were uninformative in DSR modeling.

Conversely, the proportion of depredated nests that were attributed to mammalian predators was much greater in 2023 (48% compared with 21%, 35%, and 21% in 2022, 2021, and 2020, respectively; Neuman et al. 2022, 2021a, 2021b). Continuing a trend from 2022, but in sharp contrast to recent historic trends, all nest failures caused by skunks and canids occurred in the South Bay instead of the North Bay. While nest failure attributed to canids was spread across multiple sites, skunk predation occurred only at Marina Dunes. The number of nest failures attributed to skunks at Marina Dunes in 2023 was abnormal - only five nest failures had been attributed to skunks at Marina Dunes between 1984 and 2022. Mammalian predators are managed much less than avian predators in Monterey Bay, and much of the increase in nest failures attributed to mammals were from canids in 2023, a predator group that is not managed by USDA.

The intense winter of 2022–2023 had a large effect on the beaches within Monterey Bay, and therefore on the nesting habitat available to snowy plovers. Beach structural changes due to the winter storms varied throughout the bay. In river-adjacent areas, floodwater debris was piled onto the beach (i.e., North Salinas, Monterey Dunes, and Zmudowski), creating more physical buffers between the water and the nesting habitat which may have affected chick movements or survival. Although many beaches experienced a large loss of sand and were narrower than in previous years (e.g., Moss Landing and Sunset State Beach), the dunes at some beaches were washed over and large open sand flat areas were formed providing ideal snowy plover nesting habitat (e.g., Salinas River NWR and Monterey State Beach). The expansion of habitat eastward can especially be seen in the location of nests at Salinas River NWR compared with recent years (see Appendix A for nest maps). Additionally, breeding activity appeared to be delayed by these winter storms, as the first nest was initiated about a month later than it had been in recent years (March 24th compared with late February in recent years). The median clutch initiation date of May 13th was only six days later than in 2022, however, likely indicating plovers were ready to nest but were simply waiting for winter conditions to pass. It is also of note that the pond in Marina Dunes was dry for the first time this year despite the wet winter, which led to a much higher number of nests in that area than recent years. Sand removal at this location by the CEMEX Lapis Industrial Sand Marina stopped at the end of 2020 which likely contributed to the pond drying up, although winter storms may have also contributed by depositing sand across this back dune area.

The previous winter's storms and cold weather also may have impacted the overwinter survival of adult snowy plovers. The overall breeding population declined from 2022 to 2023 and the return rate of banded birds showed this may have largely been due to a decrease in adult female survival. While male return rates were close to the previous decadal average, female return rates were much lower. This follows previous findings that adult female plovers have lower survival during winters with long cold periods (Stenzel et al. 2023).

Banded snowy plover chicks. Photo credit: Stephanie Coates, Point Blue

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Left to Right: Snowy plover eggs, banded snowy plover chick, banded snowy plover adult. Photo credits: Stephanie Coates, Esther Haile, George Cummins, respectively (all Point Blue)

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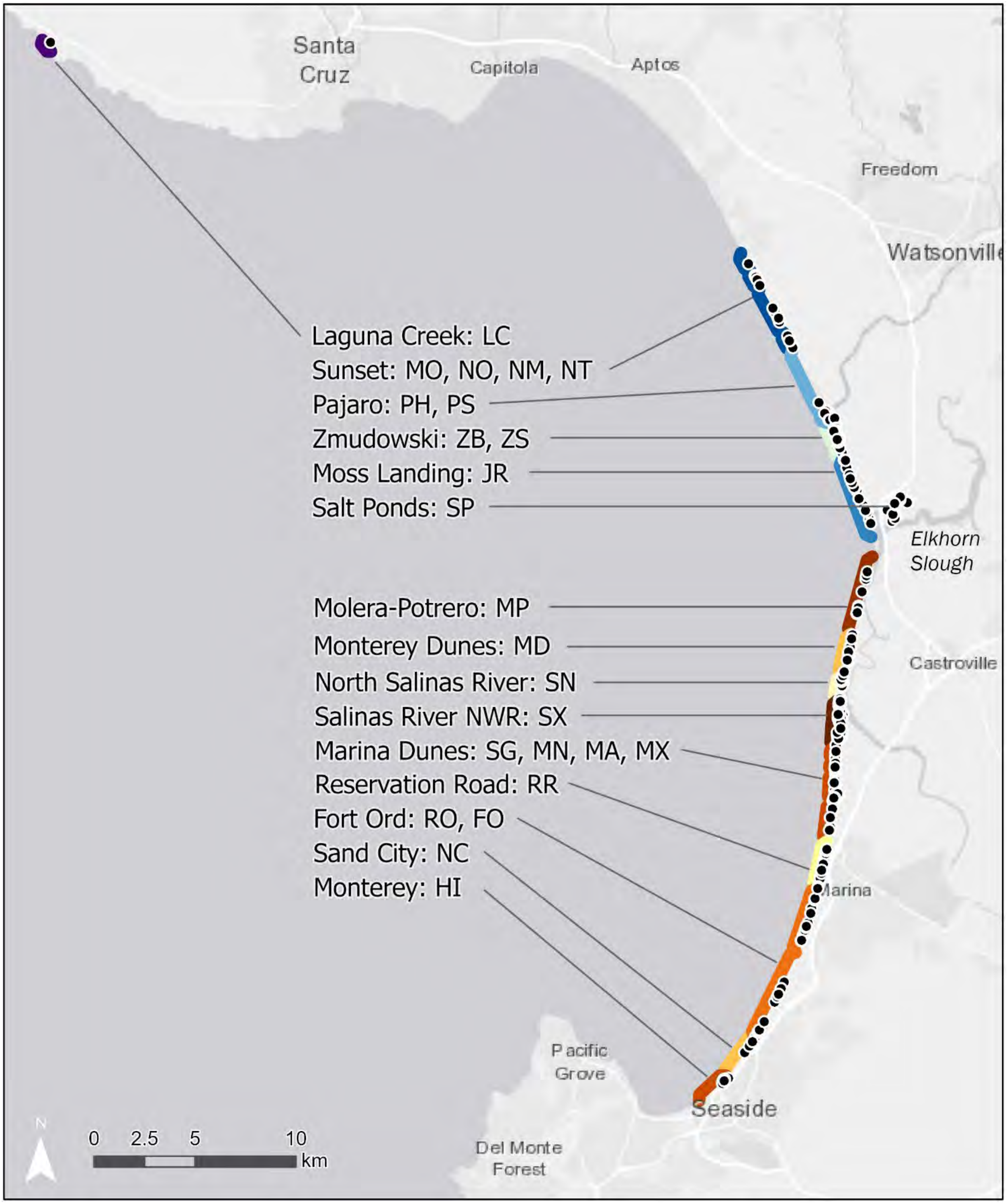
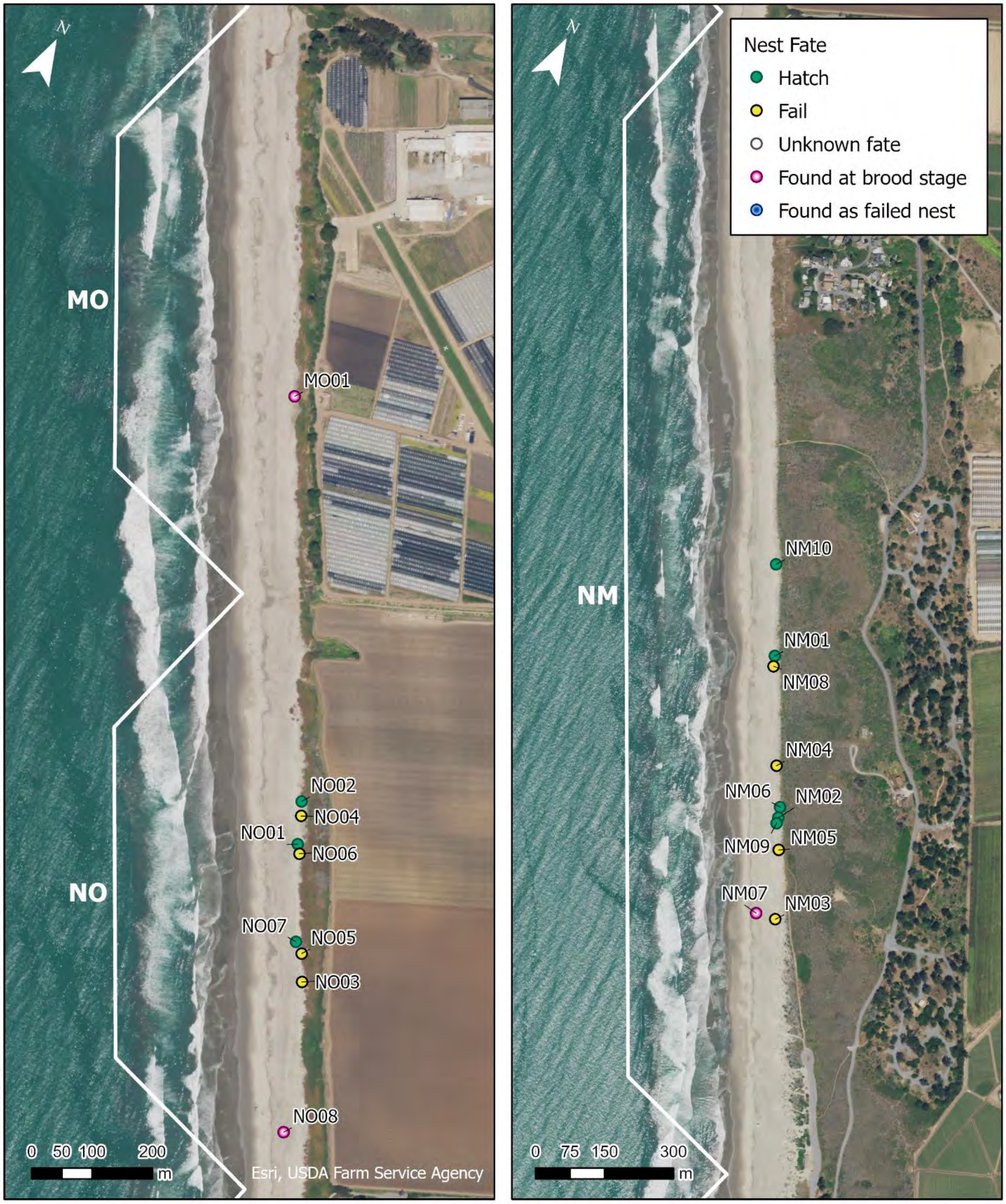
Snowy plover chicks. Photo credit: George Cummins, Point Blue

APPENDIX A: NEST MAPS

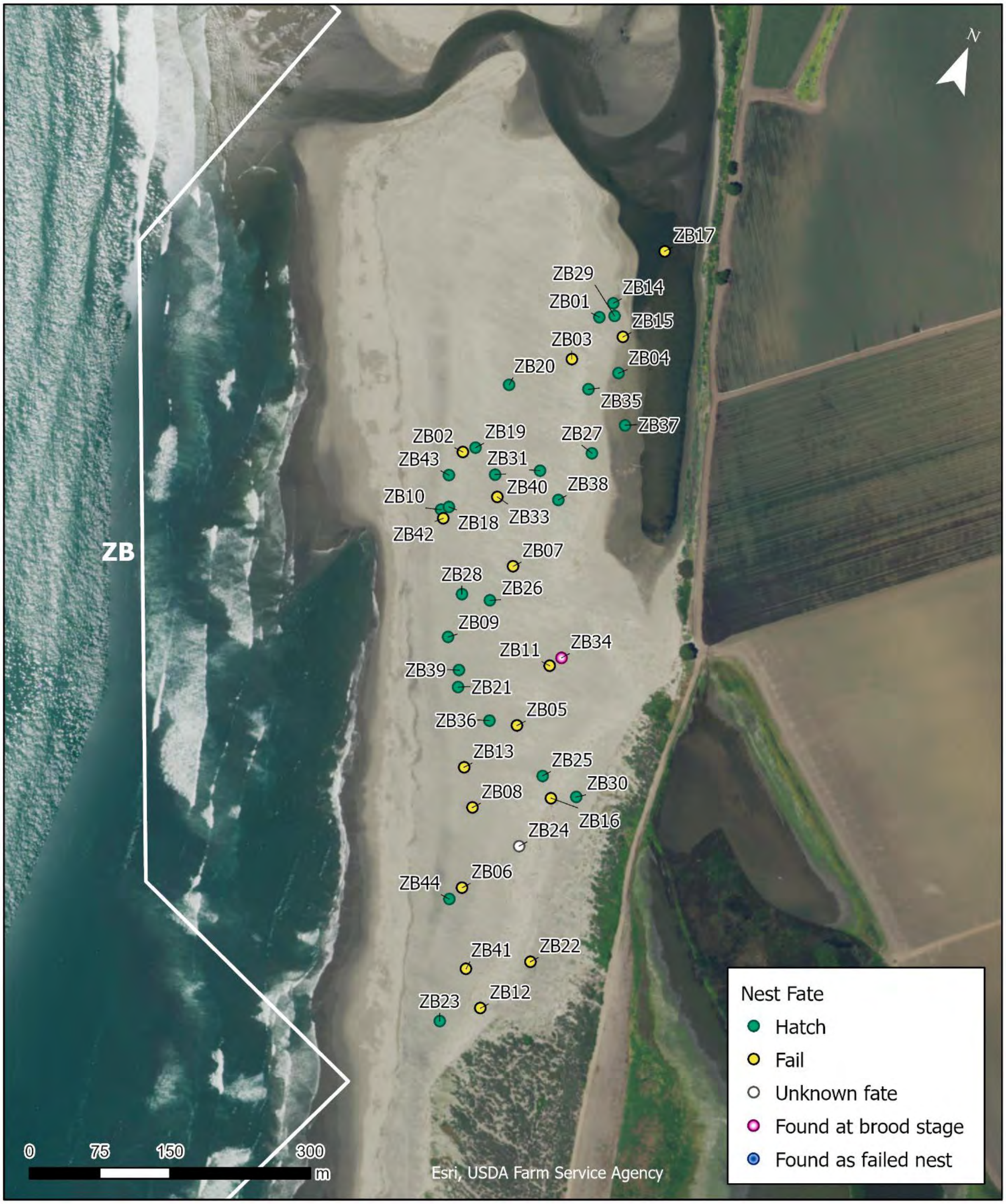


A-1. Overview of snowy plover nest locations in the Monterey Bay area in 2023 with blue colors representing North Bay sites and orange colors representing South Bay sites. One nest at Laguna Creek (purple) is in northern Santa Cruz County.

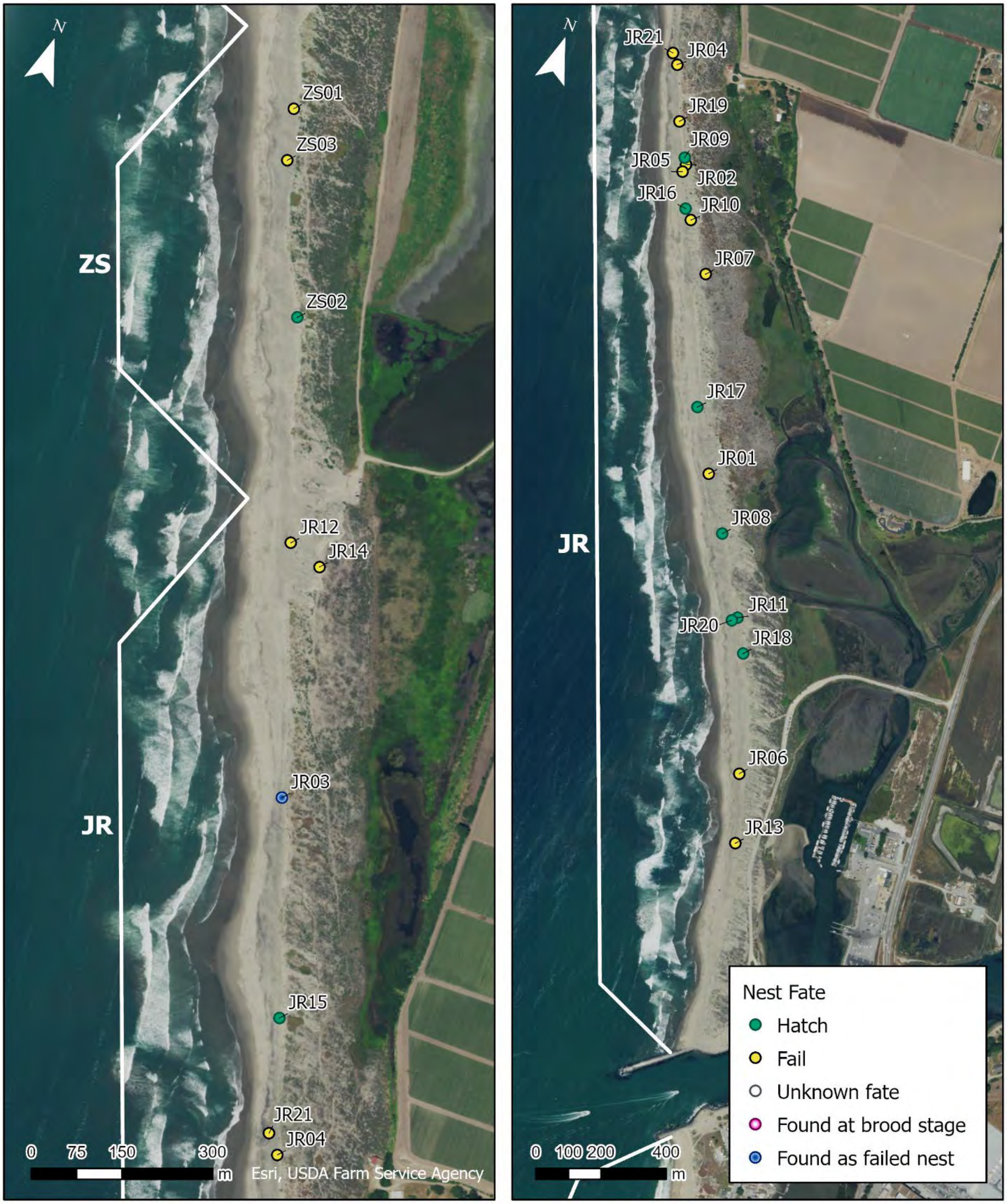


A-2. Snowy plover nest locations north of and at Sunset State Beach in 2023. Basemap imagery from May 2022.

A-3. Snowy plover nest locations at Sunset State Beach and south to the Pajaro River mouth in 2023. Basemap imagery from May 2022.

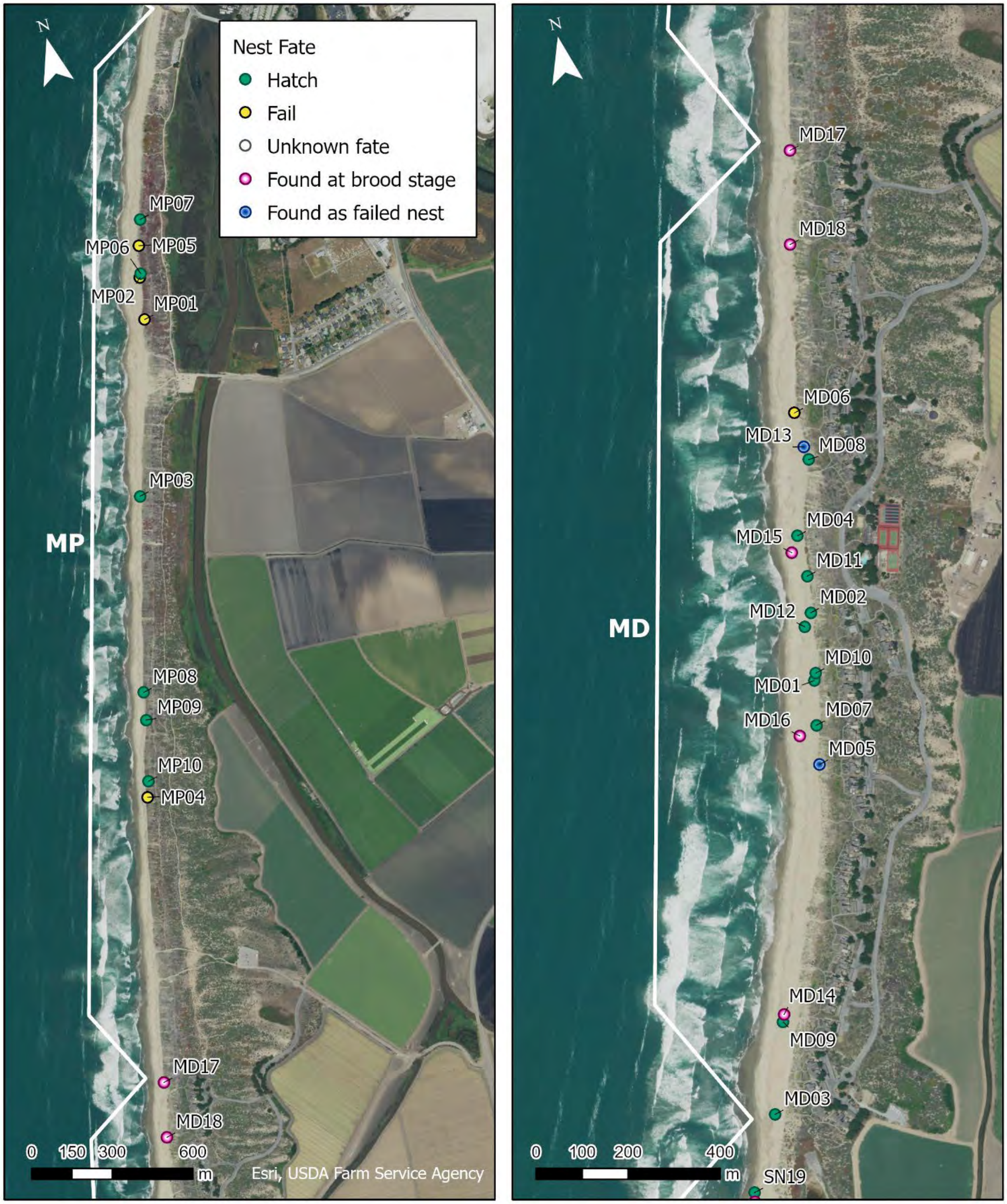


A-4. Snowy plover nest locations in the northern portion of Zmudowski State Beach in 2023. Basemap imagery from May 2022.

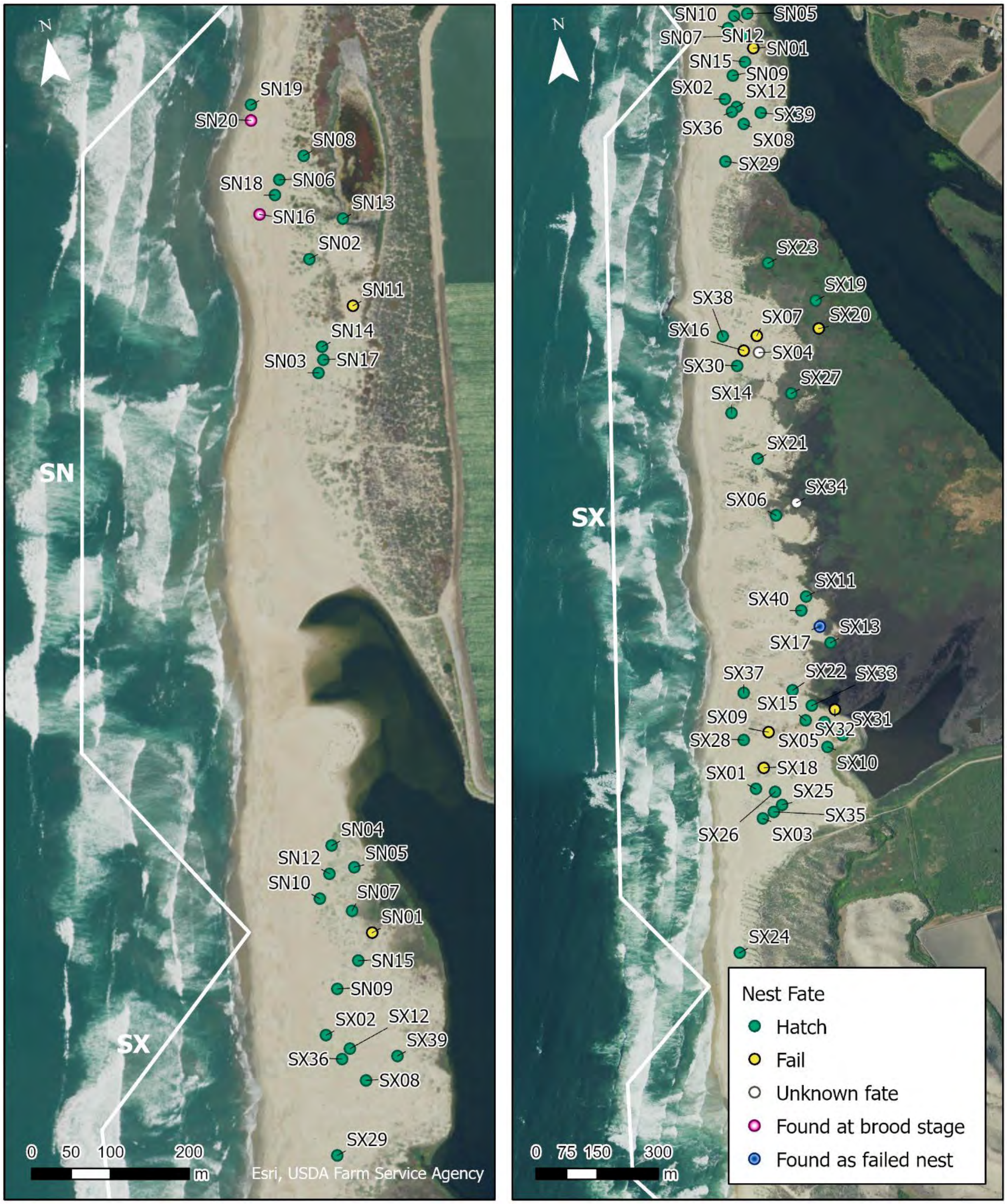


A-5. Snowy plover nest locations in the southern portion of Zmudowski State Beach and at Moss Landing State Beach in 2023. Basemap imagery from May 2022.

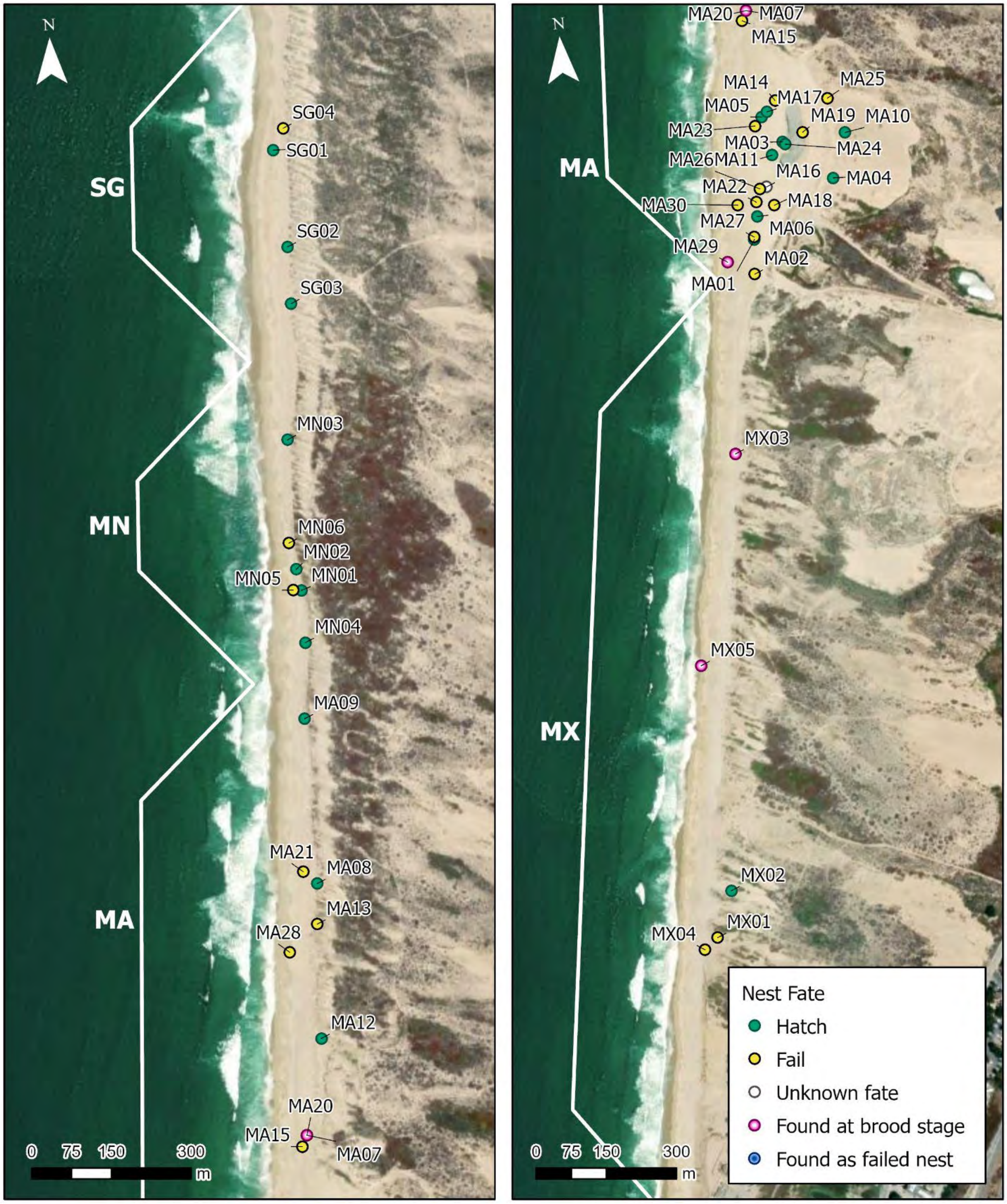
A-6. Snowy plover nest locations at the former salt ponds in the Moss Landing Wildlife Area in 2023. Basemap imagery from May 2022.



A-7. Snowy plover nest locations at the Molera-Potrero and Monterey Dunes Colony portions of Salinas River State Beach in 2023. Basemap imagery from May 2022.



A-8. Snowy plover nest locations in the North Salinas River portion of Salinas River State Beach and in Salinas River National Wildlife Refuge in 2023. Basemap imagery from May 2022.



A-9. Snowy plover nest locations at Marina Dunes in 2023. Basemap imagery from May 2022.

A-10. Snowy plover nest locations at Reservation Road portion of Marina State Beach and northern portion of Fort Ord Dunes State Park in 2023. Basemap imagery from May 2022.

A-11. Snowy plover nest locations at Fort Ord Dunes State Park, Sand City, and Monterey State Beach in 2023. Basemap imagery from May 2022.

APPENDIX B: DETAILED AREA DESCRIPTIONS

For reporting purposes, we divide the study area from north to south and describe approximate area boundaries, land ownership and management, list site codes (in parentheses), and refer to corresponding area maps in Appendix A as follows:

Northern Santa Cruz County

Laguna Creek Beach (LC): Located 10km north of the city of Santa Cruz, this cliff-backed pocket beach is approximately 600m long and is part of Wilder Ranch State Park.

Seabright Beach (BB): From the mouth of the San Lorenzo River south to the Santa Cruz Harbor's north jetty and adjacent to the City of Santa Cruz. Seabright Beach is owned and managed by California State Parks and is part of Twin Lakes State Beach (not depicted on a map in Appendix A).

North Bay Region

Sunset-Manresa (MO, NO, NM, NT): From the northern boundary of Manresa State Beach south to the boundary of the north end of the Pajaro Dunes Shorebirds development and Sunset State Beach in Santa Cruz County. This beach is owned by California State Parks and private owners and managed by State Parks and includes all of Manresa State Beach and the northern portion of Sunset State Beach (Appendix A-2&3).

Pajaro (PN, PH, PS): From the north end of the Pajaro Dunes development south to the Pajaro River mouth, Monterey County, and includes the beach north of the river and west of the Pajaro Dunes residential development, including the Palm Beach unit of Sunset State Beach as well as the sand spit on the north side of the Pajaro River mouth. This beach is owned and managed by California State Parks and includes portions of Sunset State Beach and Zmudowski State Beach (Appendix A-3).

Zmudowski (ZB, ZS): From the Pajaro River mouth south to the main parking access of Zmudowski State Beach. This beach is owned and managed by California State Parks and is part of Zmudowski State Beach (Appendix A-4&5).

Moss Landing (JR): Approximately the southern third of Zmudowski State Beach and all of the shoreline of Moss Landing State Beach, with the southern boundary located at the mouth of Elkhorn Slough at Moss Landing Harbor and the northern boundary located at the main parking access of Zmudowski State Beach. This beach is owned and managed by California State Parks (Appendix A-5).

Salt Pond Region

Salt Ponds (SP): This area includes approximately half of the former salt ponds adjacent to the western terminus of Elkhorn Slough that have been converted to managed, diked wetlands and are now encompassed within the California Department of Fish and Wildlife's (CDFW) Moss Landing Wildlife Area (Appendix A-6).

South Bay Region

Molera-Potrero (MP): From the Sandholdt Road parking lot in Moss Landing south to the northern boundary of the Monterey Dunes Colony. This beach includes the northern portion of Salinas River State Beach and is owned and managed by California State Parks (Appendix A-7).

Monterey Dunes (MD): From the northern to the southern end of the Monterey Dunes Colony, a beachfront residential development. This beach includes the middle portion of Salinas River State Beach and is owned and managed by California State Parks (Appendix A-7).

North Salinas River (SN): From the southern boundary of the Monterey Dunes Colony south to the Salinas River mouth. This beach includes the southernmost portion of Salinas River State Beach and is owned and managed by California State Parks (Appendix A-8).

Salinas River National Wildlife Refuge (SX): From the Salinas River mouth south to the northern boundary of Martin Dunes, including the sand spit on the southern side of the Salinas River mouth, and the extensive open dunes of the refuge. This beach is owned and managed by USFWS (Appendix A-8).

Marina Dunes (SG, MN, MA, MX): From the southern boundary of Salinas River NWR south to Reservation Rd. This beach is owned by the Big Sur Land Trust, private owners, Monterey Peninsula Regional Parks District and is managed with assistance from USFWS and California State Parks (Appendix A-9).

Reservation Road (RR): From Reservation Road south to the Lake Court beach access for Marina State Beach. This beach is owned and managed by California State Parks and is part of Marina State Beach (Appendix A-10).

Fort Ord (RO, FO): From the southern boundary of Marina State Beach south to the southern boundary of Fort Ord Dunes State Park. This beach is owned and managed by California State Parks and is part of Fort Ord Dunes State Park (Appendix A-10&11).

Sand City (NC): From the southern boundary of Fort Ord south to West Bay Street in Sand City. This beach is owned by private owners, the City of Sand City, Monterey Peninsula Regional Parks District and California State Parks (Appendix A-11).

Monterey (HI): From West Bay Street in Sand City south to the City of Monterey. This beach (referred to in previous reports as Del Monte) is owned and managed by California State Parks and is part of Monterey State Beach (Appendix A-11).

Snowy plover protected nesting area at Moss Landing. Photo credit: George Cummins, Point Blue

APPENDIX C: MONITORING METHODS

Each year an annual monitoring plan is developed that identifies specific goals, with targets to achieve implementation of these goals. Our overarching goal is to find all nests in each breeding area and determine nest fate and causes of nest loss to inform management. To determine annual productivity, we band a subset of chicks with an overall goal of banding 50% of all chicks, with our banding stratified spatially among sites and temporally across the breeding season. The "Study Area and Annual Monitoring Objectives" section of the main report details the specific annual goals identified in the annual monitoring plan.

Monitoring

Field surveys for nesting snowy plovers are conducted during daylight hours, from March-September at selected active breeding areas (see Appendix B for detailed site descriptions). Most daily monitoring is conducted between 0600 and 1400 hours with each site surveyed 1–4 times per week. Monitoring effort among sites each year is unevenly distributed, with some areas receiving more effort. Factors affecting the distribution of effort include the difficulty of monitoring (complex or larger areas require more effort), personnel capacity, site logistics (e.g., ease of access), observer experience, and other annual circumstances. We collect information on survey duration and the number and type of human activities observed within the study area.

Nests are located by conducting field surveys in areas that have or are suspected to have breeding plover activity. Nests are located by visually searching habitat for nest scrapes and nests and by observing nesting plovers and their behavior. We record the latitude and longitude of each nest with Global Positioning System (GPS) units that are accurate to within 3m. We also used GPS units to create proxy nest locations for all nesting attempts that were found as broods of chicks (i.e., after hatching) by creating a location at the first place a brood was observed. All nest and brood locations are plotted on nest maps for each area.

We estimate clutch hatching dates from egg laying dates, when known, or from egg flotation (Hays and Lecroy 1971). Projected hatching dates are refined by examination of eggs for cracked shells, tapping chicks, or peeping chicks in the 4–6 days leading up to the projected hatching date.

Attributing Nest Fate and Cause of Loss

For an egg to be counted as hatched, one of the following criteria must be met: 1) chick(s) observed hatched in nest cup, 2) chick(s) observed with a known-identity attending parent during the chick-rearing period, 3) chick(s) observed near the nest location repeatedly without attending adult during the chick-rearing period, all evidence at nest site is consistent with one or more eggs hatching, and there is no counterevidence to suggest the chick(s) association with another nest, or 4) pip fragments must be observed in or adjacent to the nest after suspected hatch.

When eggs disappear or are destroyed prior to the projected hatch date, causes of nest failure are determined by examining evidence at nests (e.g., damaged eggshells, predator tracks, evidence of tide wash). Cause of nest loss falls into three general categories: Environmental, Predator/Human, and Abandonment/Viability. Each is further divided into more specific causes of loss based on the observed evidence. When the cause of failure is unknown because evidence at the nest was lacking, we categorize the cause of failure as unknown. In certain cases, with no visible cause, we assign the nest failure to an avian predator "event" when it meets both of the following criteria: the nest was within or adjacent to an area where nest(s) were confirmed to have been depredated by an identified avian predator, and the nest was lost during a similar time interval (+/- 3 days). Similarly, a "tide event" is assigned when the evidence matches criteria for a tide damaged nest, but eggs cannot be found and the time since last check is less than seven days. Nests for which the fate of at least one egg was known are considered "known fate" nests.

Color-banding

We use unique combinations of four individual color-bands to mark a sample of chicks to estimate fledge rates and annual return rate of fledged juveniles. We also band a sample of unbanded adult plovers to track nesting attempts, brood locations, and annual return rates. We trap adults at or near the nest using snare mats and capture chicks at or near the nest by hand at the time of hatching. We monitor brood survival throughout the chick-rearing period primarily by observing parental behavior that indicates the presence of chicks (e.g., lure displaying) and by directly observing chicks with attending males (or females). We consider banded chicks to have reached fledging age if they survive 28 days or more after hatching. Because unbanded chicks within and among similar-age broods are indistinguishable from one another, they are determined to have fledged only when they are directly observed with the attending parent at or within a few days after the fledge date.

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Banding a snowy plover chick with color bands. Photo credit: George Cummins

APPENDIX D: ANALYSIS METHODS

Breeding Population Size

To estimate the Monterey Bay breeding population size, we have used three methods: 1) a monitoring estimate (1985–2015), 2) a monitoring estimate that included estimation of probable banded and unbanded breeders (2016–2019), and 3) a window survey estimate (2002–present).

For Method 1 we derived the total number of breeders from our monitoring across the duration of the breeding season (March–August) by directly confirming the identities of individual plovers incubating nests or attending broods, or indirectly by using small cameras deployed at nests.

For Method 2, we summed the identified individuals using Method 1 with the probable number of additional breeders based on their observed presence within the study area using an evidence-based protocol. This protocol included assessing the evidence for nesting for each candidate; evidence was based on the number of sightings in May and June, the duration of presence in the study area, breeding behaviors exhibited (e.g., paired, broody, copulating, scraping, lure display), the individual's history of confirmed nesting, and natal origin. To derive the number of probable unbanded breeders, we applied the ratio of confirmed to probable banded breeders to the estimated number of confirmed unbanded breeders. This produced a breeding number for each sex that was the sum of *confirmed banded breeders + confirmed unbanded breeders + probable banded breeders + probable unbanded breeders*. For each sex, we estimated the minimum number of confirmed unbanded breeding adults by determining the maximum number of simultaneously extant nests with unbanded parents and subtracting the number of unbanded breeding adults that were subsequently banded on nests during the nesting season.

For Method 3, we conduct a single, coordinated survey of all breeding sites within the study area during the third week of May as part of the rangewide window survey following methods outlined in Elliot-Smith and Haig (2006). This annual window survey is the primary method used by USFWS to estimate the size of the Pacific coast population of snowy plovers and to monitor population status over time. Beginning in 2020 the proportion of color-banded breeders was no longer adequate to derive the breeding population size from monitoring across the season (Method 1) or to use Method 2; instead, we applied a 1.22 correction factor to the window survey estimate, based on the relationship between the monitoring estimate and the window survey estimate from 2002–2015, to estimate the actual breeding population size. This correction factor is derived from Monterey Bay data and should be considered specific to this region.

Return Rates

We calculate annual return rates for banded plovers of each sex as the proportion of confirmed or probable breeders from the previous year that return to breed in the current year (as confirmed or probable breeders). Probable breeders are individual banded plovers that were never confirmed on a nest, but likely either had a nest we never found or were on a nest that we monitored but failed to confirm the identity of one of the pair. We use a rubric to score individual plovers that were seen during the breeding season to decide if we have enough evidence to call them probable breeders. This rubric includes the number and timing of sightings, the number and timing of paired or other nesting behavior (e.g., lure displays or broody behavior), and the individual plover's recent nesting history. We also report the annual return rate of juveniles as the number of chicks from the previous year determined to have fledged (by the current breeding season on Monterey Bay) with evidence of breeding (as confirmed or probable breeders) in the current year. Return rates are expressed as percentages.

Nest Success and Fledge Rates

Apparent Nest Success and Fledge Rates

We calculate apparent nest success, or clutch hatch rate, by dividing the number of known fate nests that hatched by the total number of known fate nests for each site and for the study area. Nests found as broods are excluded from clutch hatch rate calculations.

To calculate fledge rates we divide the number of banded chicks that are confirmed to have fledged by the total number of chicks that were banded. Beginning in 2020, we applied the framework developed in Henkel et al. (2020) to estimate the error around the fledge rate. In this analysis, we simulated various levels of banding at 10% intervals (e.g., 50%, 60% etc.) by resampling from our data series from 2003-2012 in which more than 95% of hatching chicks were banded. For more detailed information see Henkel et al. 2020. Site-specific fledging success is based on the broods that originate from the nests that are located at each site, even in cases where broods moved to adjacent areas before fledging. In addition to the fledge rate for the banded sample, we report minimum and maximum numbers of unbanded chicks that fledge, but we do not report fledge rates for unbanded chicks. Beginning in 2015, we modified our study design, including not attempting to band every chick that hatched, so comparisons with trends in reproductive rates from 2015 onward should be interpreted with this in mind. All rates are expressed as percentages. We analyze trends using a Kendall rank correlation test in Program R (R Core Team 2022).

Nest Daily Survival Rate

We calculate maximum likelihood estimates of daily survival rate (DSR) for nests (beginning in 2022). We complete DSR modeling in R version 4.2.2 (R Core Team 2023) using the RMark package (Laake 2013). DSR analysis requires that nests have a known fate and an exposure time >0, meaning that nests must be monitored for at least one day during the nesting period. We include only Monterey Bay nests in DSR modeling, resulting in the exclusion of one nest at Laguna Creek, northern Santa Cruz County, in 2023.

We create models to 1) produce constant DSR estimates by location and 2) evaluate *a priori* hypotheses about predictors of nesting success. Although nests can be grouped at several location levels based on the site, focal area, and region of Monterey Bay, we report only bay-wide and region (North vs. South Bay) here because small sample sizes at the site and focal area level preclude meaningful interpretation at many sites. For predictive models, we include time covariates (unadjusted, quadratic, and cubic functions) to examine effects over the season and a nest age covariate to examine effects over the nesting period. Failing to account for nest age can lead to biased results, especially if nests are found later in the nesting period or when nest age when found differs between comparison areas (Weiser 2021). We examine covariates related to nest density at multiple scales (number of nests in a 1ha and 6ha circular plots (approximately 56 and 138m radii, respectively), and within increasing radii of 250, 500, 1000, 2000, 5000 meters) and a measure from each nest to its nearest neighbor. These metrics use simultaneously active nests only, meaning sequential nesting attempts by the same plover(s) do not artificially increase nest density or reduce the distance to the nearest nest. We test an estimate of predator pressure as a covariate in 2023 using the maximum number of crows and ravens observed in the window of time between the clutch initiation date and 32 days post clutch initiation, derived from observations recorded by surveyors in disturbance-predator logs.

To better examine the effect of predator management, we incorporate a “Protection Factor” covariate into the DSR models. A higher Protection Factor equates to a higher level of predator management and was assessed for each nest. We evaluate separate estimates for predator species based on removal data provided by the Wildlife Services unit of the USDA. To test whether individual predators have disproportionate impact, we make individual protection factors for each removal event, as well as stacked protection factors for each species and for corvids. The three components of the protection factor are 1) number of individuals removed; 2) distance between the removal location and the nest; 3) timing of the removal in relation to when the nest was active, with the assumptions that more individuals removed and a shorter distance between removal location and nest site would equate to greater protection. We also assume that there would be maximum protection if a predator were removed on clutch initiation date, with decreasing protection after that date until the estimated hatch date. Before clutch initiation date, we estimate a more slowly decreasing level of protection on the grounds that with increasing time since the removal, corvids would have the opportunity to immigrate and increase specialization in plover nest depredation. For this new measure, we use a final version of a Protection Factor that scales each component from 0 to 1 with 0 equating to no protection and 1 equating to the most protection and incorporating them into the formula: recency*(removals + distance). Previous iterations included unscaled variables combined in multiple ways which were refined through discussion and hypothesized influence of each variable. However, DSR models that included any variety of Protection Factor metrics we incorporated were not highly ranked in our 2023 candidate model set.

We convert DSR estimates to percent survival by exponentiating DSR by 32, the median number of days in the nesting period (laying and incubation stages). It should be noted that snowy plover egg lay and incubation stages vary in length, with both generally becoming shorter by one day as the breeding season progresses. However, we use a static estimate of a 32-day nesting period to predict hatch dates from egg floating so that we are less likely to miss hatches. Unless we find a nest during egg-laying and are therefore able to assign an exact date, clutch initiation dates are also based off a 32-day nesting period. If the biological median nesting period for snowy plovers (33 days) were to be used instead, estimated percent survival would decrease because nests would need to survive an additional day.

Cause of Nest Loss Over Time

We examine predator-caused nest loss in more detail than other causes of nest loss due to its relevance to management. Using density plots, we plot the probability per unit of time of a nest hatching, failing due to any predator, or failing due to other causes, or failing due to unknown causes. Predator-caused losses include avian, mammalian, and unknown predator categories. Other causes of loss include abandonment, human-caused loss, environmental causes, and egg viability issues. We include only known fate nests and assign the plotted date for each nest as the hatch date (for hatched nests) or the midpoint between the date that a nest is last observed active and the date it is found lost (for failed nests). Each frequency count for a category is standardized by the total number of occurrences over time within that given category.

Breeding Efficiency

Breeding efficiency (BE) is the ratio of the number of fledglings to the number of eggs laid in a given area (Colwell et al. 2018) and we conservatively calculate BE as the minimum number of fledglings divided by the minimum number of eggs laid for overall and site-specific estimates. We include data from any unknown fate nests and nests that were found as a brood because this metric is to be used as a general overall measure of productivity that can be made simply by knowing how many eggs were laid and how many chicks survived to fledging in a given area. Individual plovers may move around within the breeding season which complicates the calculation of how many individuals are breeding within an area (and therefore makes calculating the number of fledglings per male difficult). Conversely, the BE at any geographical scale is easily calculated if the number of eggs laid and confirmed fledglings can be recorded. We did not consider the size of a site when calculating the BE as this may mask productive yet long stretches of beach with lower breeding density. In the future, in addition to calculating BE, standardizing the BE by the size of each site may inform managers of where dense areas of breeding productivity occur on the landscape. Instead of standardizing by size, we created maps of BE interpolated across the landscape with ArcGIS Pro (Esri 2022) using kriging. Variance for interpolated BE estimates is not displayed in the map for the 2023 season but can be expected to increase where there are fewer data points.

This metric has been found to be highly correlated with the number of fledglings per male, with a BE of ~0.2 and higher equaling at least 1.0 fledglings per male (Colwell et al. 2018). We also found a strong correlation between BE and the number of fledglings per male when using Monterey Bay data from 1997 to 2014 (adjusted R^2=0.95, p-value<0.001). During this time ~90% of all chicks were banded and the number of fledglings per male in a given year could be calculated directly. Further, we found the same pattern in our data that a BE of 0.18 and higher (or 0.2 to be conservative) equals at least 1.0 fledglings per male (Figure D-1). We did not find that the egg efficiency (the minimum number of chicks hatching divided by the minimum number of eggs laid) was correlated with the chick efficiency (the minimum number of fledglings divided by the minimum number of chicks hatching), indicating that survival pressures on these two life stages are separate (adjusted R^2=-0.002, p-value=0.34). Management of predators and other survival pressures that affect snowy plovers differently at the egg and chick stages should both be considered to increase breeding efficiency and overall productivity.

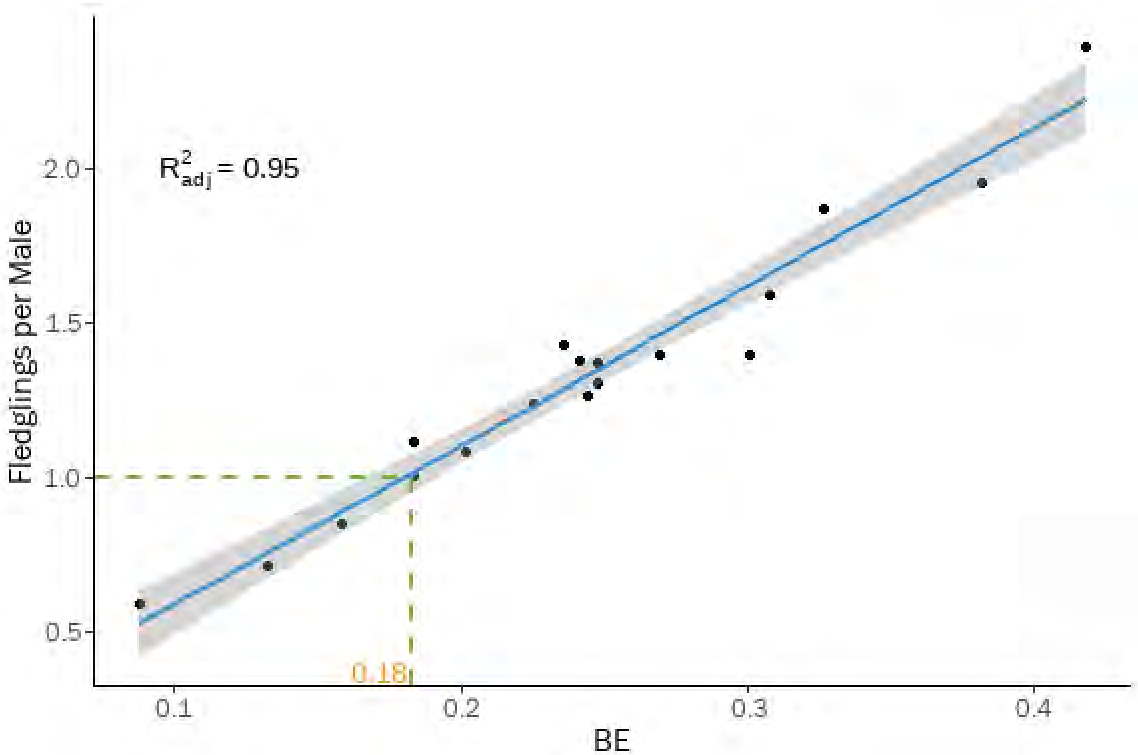

Figure D-1: The breeding efficiency (BE) and the number of fledglings per male in the Monterey Bay region from 1997 to 2014. The dots represent the value for each year and the blue line is the regression line with a gray confidence band of 95%. The green dashed line represents the BE (0.18) at the recovery target of 1.0 fledglings per male.

The relationship between BE and the estimated number of fledglings per male should be investigated further to understand the mechanisms behind this apparent correlation and how varying levels of color banding effort may influence it. Using Monterey Bay data from 1984 to 2023, we found no significant correlation between the percent of chicks banded in a given year and the BE (adjusted R^2=-0.005, p-value=0.37), indicating that in our system the level of color banding effort does not influence our ability to calculate BE. However, a minimum of around 50% of the total number of hatching chicks has always been banded in Monterey Bay during this time span, so it is still unknown how no or low amounts of color banding would affect the estimation of BE.

Further, if the detection of fledglings versus eggs is different between sites, this could influence comparisons of BE between them. This difference in detection between fledglings and eggs could occur due to monitoring effort differences or detectability differences between fledglings or nests across sites. For example, if less monitoring effort at one site leads to proportionally less failed nests being found (i.e., less eggs found) but a proportionally equal number of fledglings found relative to the true number at that site, the BE could be artificially inflated when compared to a site with more monitoring effort. Similarly, if fledglings are more easily detected at one site compared with another site with similar monitoring effort, the BE at that site may be artificially higher in comparison. However, if more effort at a site leads to a proportional increase of the true number of both eggs and fledglings discovered, or effort is scaled up at sites with lower detectability of either nests or fledglings, then BE should still reflect an accurate comparison between sites.

Using data from across Monterey Bay between 2008 and 2023, we found no significant correlation between field effort and either the minimum number of eggs (adjusted R^2=-0.014, p-value=0.39) or minimum number of fledglings observed (adjusted R^2=0.009, p-value=0.31). This indicates that our overall level of field effort appears to be enough to find most nests and fledglings within our survey areas, and our measures of BE should be unaffected by the variance in our field effort year over year. Additionally, following our protocols, most (if not all) of our sites are monitored on a consistent basis throughout the breeding season (if sites were monitored at different dates throughout the season, this could also influence BE). Also, because we also aim to be at a site whenever a nest hatches or fledges, our effort scales with the breeding activity at each site. If detectability of nests or fledglings is related to the number of nests occurring at a site, then our effort scales appropriately. However, if there are sites where detectability of fledglings or nests is unrelated to the amount of breeding activity, we may not be able to directly compare BE among those sites. In our case, it is possible that fledglings are easier to see at our salt ponds site than at the rest of our sites (i.e., those on the beach), while nests are harder to find. This could lead to proportionally more broods and fledglings and less nests and eggs found at this site compared with the true number. This would cause the salt ponds site to have a relatively higher BE than a given beach site where nests are easier to find but fledglings more difficult to see. We have not yet tried to quantify any detectability differences between our sites in Monterey Bay, but apart from our salt ponds site, the rest of our monitoring areas seem relatively uniform. It may be useful to conduct a resampling study using data from individual sites within the same year to determine if varying levels of effort at a specific site cause varying comparisons of BE across sites.

Monitoring Effort and Human Activities

We calculate an annual encounter rate per survey hour of humans, with all types of human activities summed into one encounter rate. We also present the encounter rate per survey hour of dogs, including on- and off-leash dogs. We analyze trends using a Kendall rank correlation test in Program R (R Core Team 2023).

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APPENDIX E: MONITORING EFFORT

Overall Monitoring Effort

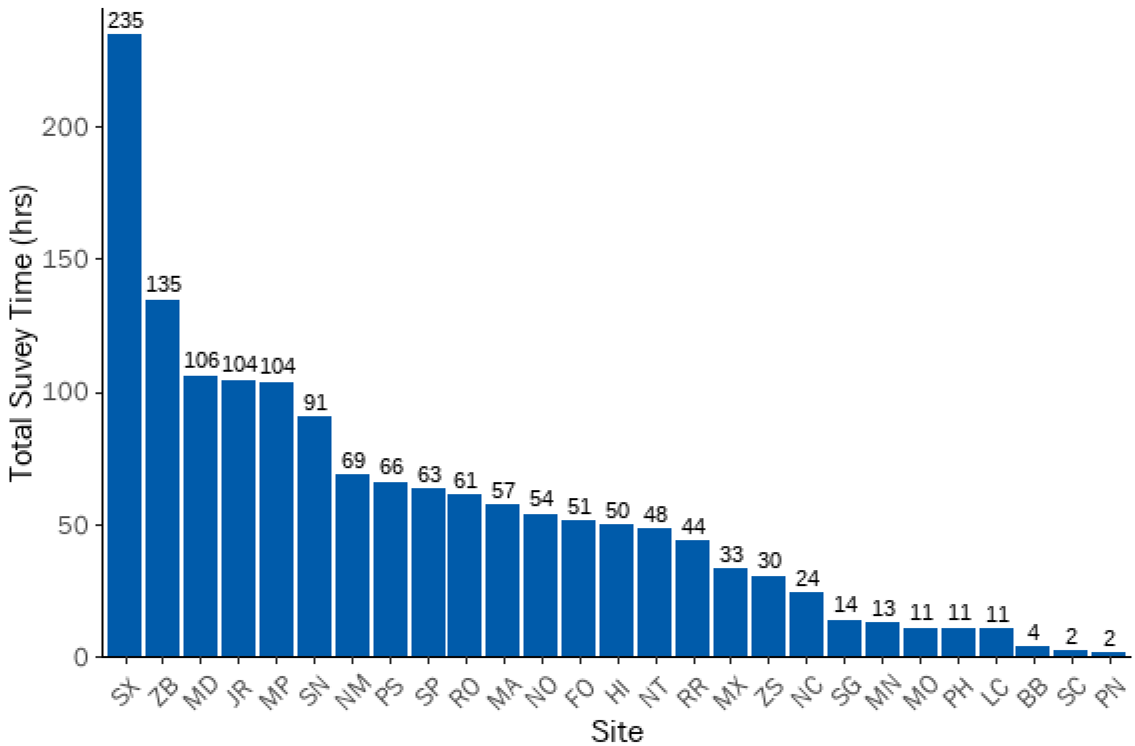

Figure E-1: *The total time spent surveying and monitoring snowy plovers at each site within the Monterey Bay region during the months of March through August, 2023. The numbers above the bars are the total survey time in hours for each site. Site descriptions are given in Appendix B.*

Snowy plover habitat near Pajaro River mouth. Photo credit: George Cummins, Point Blue

Monitoring Effort by State Park District

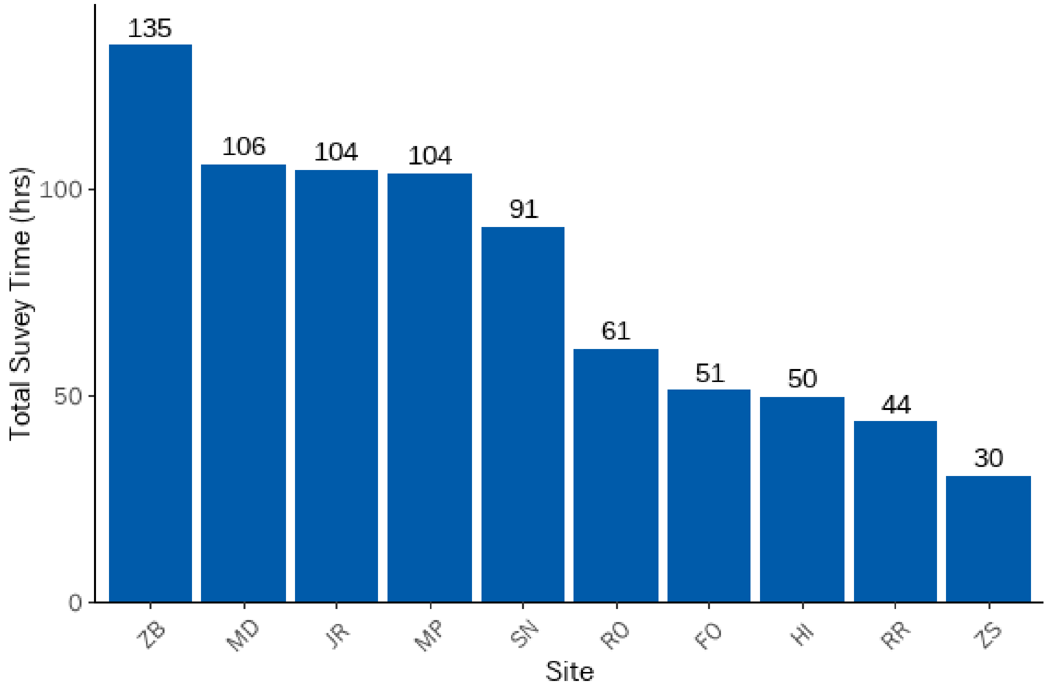

Figure E-2: *The total time spent surveying and monitoring snowy plovers at sites within the Monterey District of California State Parks during the months of March through August, 2023. The numbers above the bars are the total survey time in hours for each site. Site descriptions are given in Appendix B.*

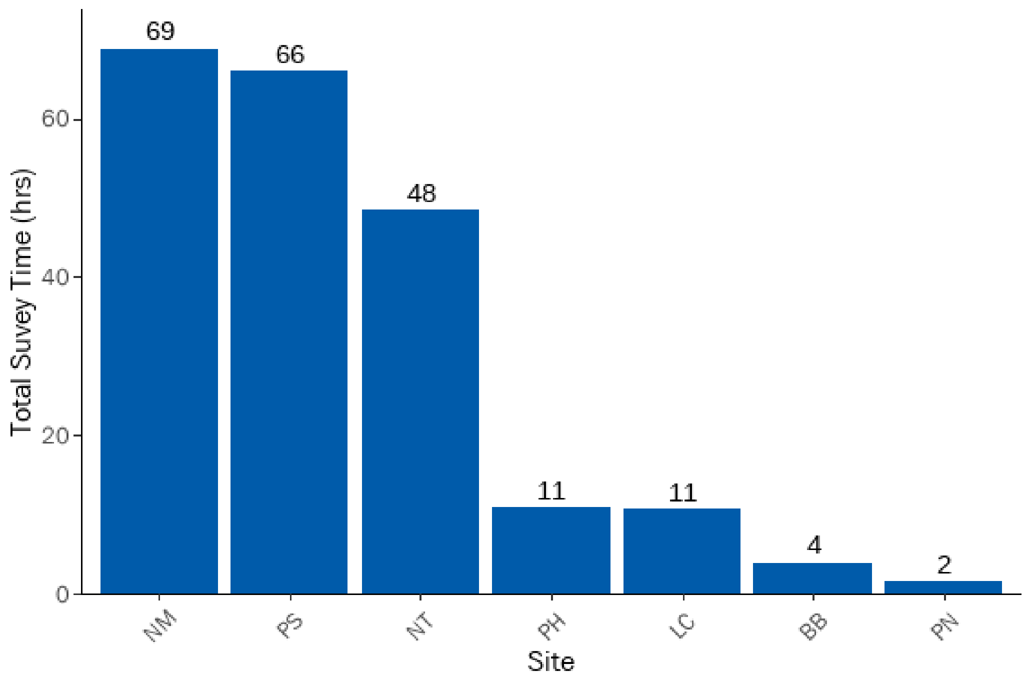

Figure E-3: *The total time spent surveying and monitoring snowy plovers at sites within the Santa Cruz District of California State Parks during the months of March through August, 2023. The numbers above the bars are the total survey time in hours for each site. Site descriptions are given in Appendix B.*

Monitoring Effort per Nest

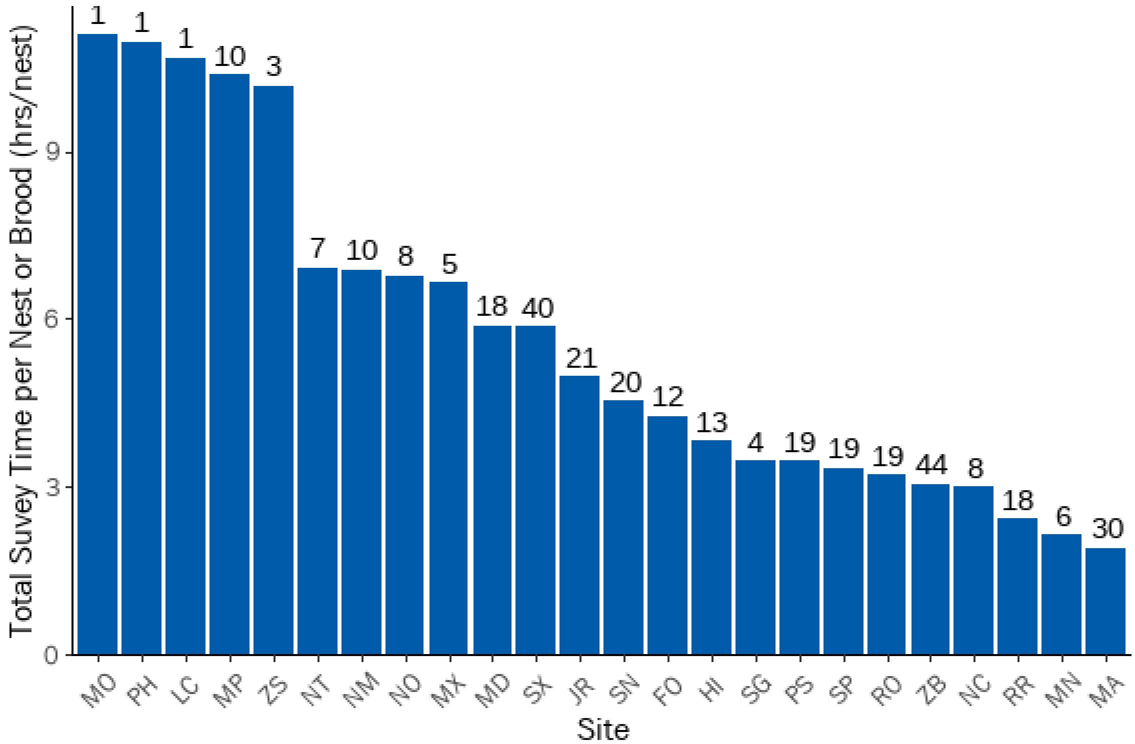

Figure E-4: *The total time spent surveying and monitoring snowy plovers per nest at each site within the Monterey Bay region during the months of March through August, 2023. The numbers above the bars are the total number of nests monitored for each site. Site descriptions are given in Appendix B.*

Snowy plover chicks. Photo credit: Stephanie Coates, Point Blue

Monitoring Effort per Nest by State Park District

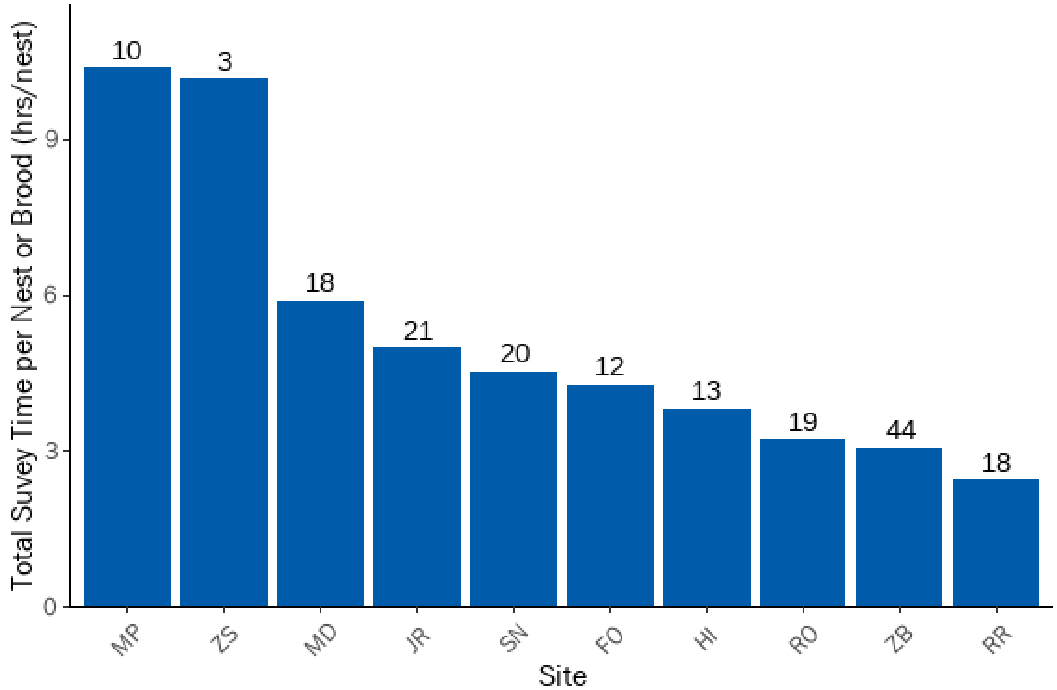

Figure E-5: The total time spent surveying and monitoring snowy plovers per nest at sites within the Monterey District of California State Parks during the months of March through August, 2023. The numbers above the bars are the total number of nests monitored for each site. Site descriptions are given in Appendix B.

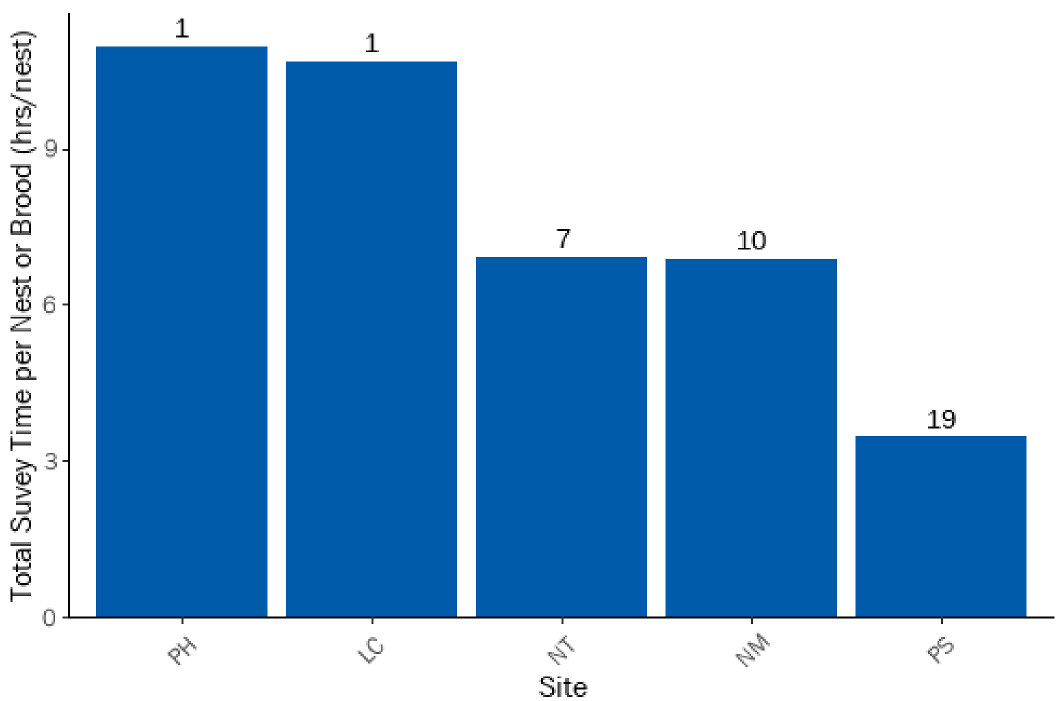

Figure E-6: The total time spent surveying and monitoring snowy plovers per nest at sites within the Santa Cruz District of California State Parks during the months of March through August, 2023. The numbers above the bars are the total number of nests monitored for each site. Site descriptions are given in Appendix B.