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Common Raven Impacts on Nesting Western Snowy Plovers: Integrating Management to Facilitate Species Recovery

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Case Study

Common raven impacts on nesting western snowy plovers: integrating management to facilitate species recovery

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Abstract: The U.S. Pacific coast population of the western snowy plover (*Charadrius nivosus nivosus;* plover) has declined due to loss and degradation of coastal habitats, predation, and anthropogenic disturbance. The U.S. Fish and Wildlife Service listed the subspecies in 1993 as threatened under the Endangered Species Act due to the population declines and habitat loss. Predation of nests and chicks has been identified as an important cause of historic population declines, and thus, most predator management actions for this subspecies are focused on reducing this pressure. In recent years, common ravens (*Corvus corax*; ravens) have become the most common and pervasive predators of plover nests and chicks, especially in areas with subsidized food sources for ravens and sites without predator management. We compiled data from a variety of sources to document the impact of raven predation on plover nesting success. We discuss current raven management and suggest several tools and strategies to increase plover nesting success, including multi-state approval for the use of the avicide DRC-1339, the use of lures and new trap types, and an increase in funding for predator management. The lack of coordinated and integrated management continues to impede the recovery of the Pacific coast plover population.

Key words: *Charadrius nivosus nivosus*, common raven, coordinated management, *Corvus corax*, nesting success, Pacific coast, predator management, species recovery, threatened species, western snowy plover

The western snowy plover (*Charadrius nivosus nivosus;* plover) is a small shorebird that nests on sandy beaches and salt pannes (e.g., salt flats or managed ponds) and relies on nest camouflage, precocial chick rearing, and inconspicuous plumage to avoid detection by predators. The Pacific coast population of the plover occurs in coastal habitats ranging from central

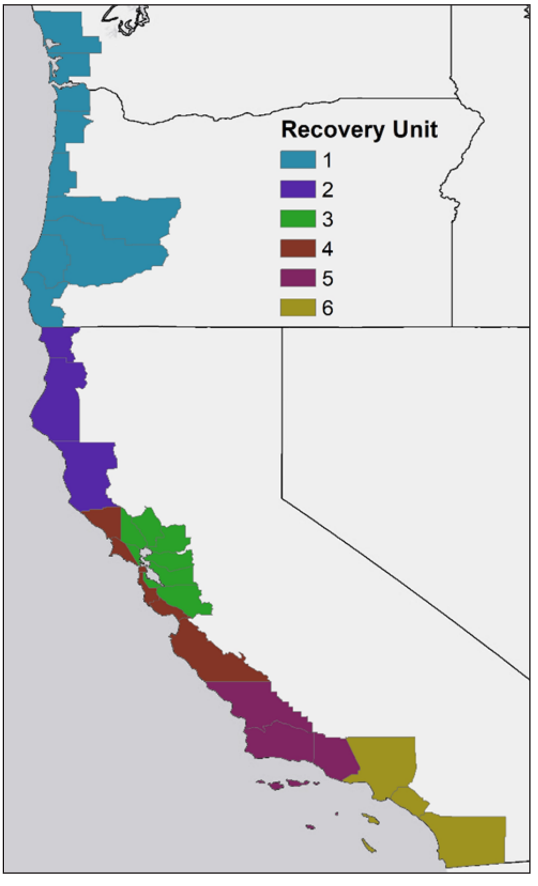

Figure 1. Map showing federally designated recovery units (by county) for the Pacific coast population of the western snowy plover (*Charadrius nivosus nivosus*) in the United States (adapted from U.S. Fish and Wildlife Service 2007).

Washington, USA, south through Baja California Sur, Mexico (U.S. Fish and Wildlife Service [USFWS] 2007, Eberhart-Phillips et al. 2016; Figure 1).

The plover was federally listed as threatened in 1993 due to a significant decline in the population size and number of occupied breeding sites (Page and Stenzel 1981, Page et al. 1991). Population declines are a result of loss and degradation of coastal beach and dune habitats, predation, and anthropogenic disturbance (USFWS 1993, 2007). Recovery efforts since the listing have focused on predator management, habitat protection and restoration, and public education and outreach. These efforts have resulted in increased reproductive success, population size, and number of occupied breeding sites in some areas. However, annual reproductive success and adult population size are still below the subspecies' recovery plan targets in most areas (USFWS 2007, 2019; Figure 2).

Plovers have been monitored within 6 recovery units (RUs) that constitute the range of the subspecies and are delineated by USFWS in the subspecies' recovery plan (USFWS 2007; Figure 1). Thus, substantial information is readily available on the 2 major facets of reproductive success, nest hatching success and chick fledging success, and current and historic approaches to predator management. Predation of plover nests, chicks, and adults is an important cause of population decline (Colwell et al. 2005, Dinsmore et al. 2017, Colwell et al. 2019), and alleviating these losses has been a main focus of management for this subspecies. Although a wide array of predators depredate plover nests (Neuman et al. 2004, Demers and Robinson-Nilsen 2012, Dinsmore et al. 2014), the common raven (*Corvus corax*; raven) has emerged as a major nest predator (Burrell and Colwell 2012, Dinsmore et al. 2014, Lau et al. 2021, Neuman et al. 2021). Over the past 60 years, raven abundance has increased in coastal California and Oregon, USA (Liebezeit and George 2002, Peery and Henry 2010, Sauer et al. 2017), and ravens have expanded their range into new areas (e.g., the central California coast; Roberson et al. 1993, Rinkert 2018).

Since listing in 1993, predator management has been implemented across the plover range, although not at all sites. The type and intensity of predator management conducted annually at plover breeding sites depends on available funding, landowner goals, public perception, regulatory requirements, and site-based constraints that influence feasibility of conducting management. Predator management has included nonlethal methods (such as hazing, trash management, and marine mammal carcass removal) and lethal removal (i.e., trapping, shooting, and the use of the avicide DRC-1339). Lethal removal has been conducted by U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Wildlife Services and private contractors under federal and state permits.

Individual nest exclosures, a technique employed to increase nest hatching rates of imperiled shorebird species (Smith et al. 2010), have also been widely used to protect nests from predators. Nest exclosures are wire cage structures that sit over the nest during the in-

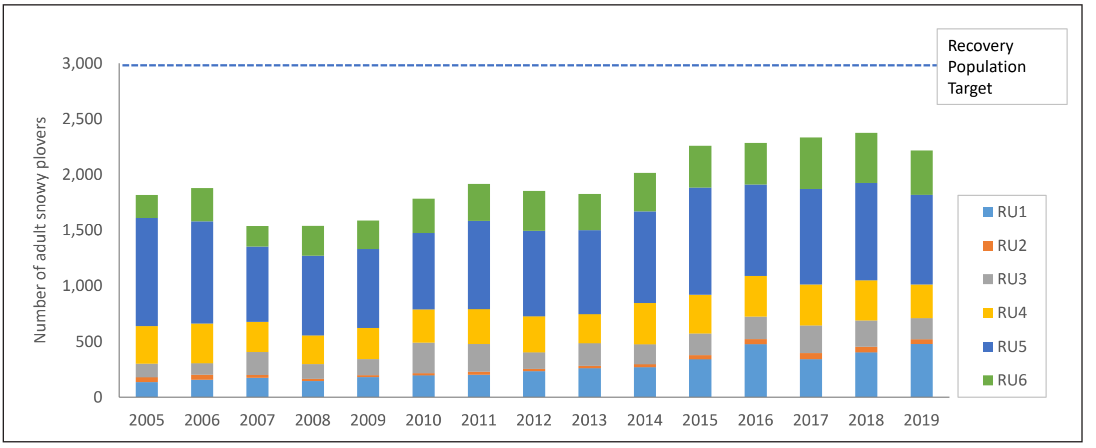

Figure 2. Western snowy plover (*Charadrius nivosus nivosus;* plover) breeding population as determined by single-day surveys in each of 6 federally designated recovery units (see Figure 1 for locations), the range-wide breeding population total, and the number of plovers required to remove this species from the endangered species list (U.S. Fish and Wildlife Service 2019).

cubation period, allowing adult plovers to pass in and out while excluding larger animals. Although exclosures have been demonstrated to increase plover hatching success, they can also increase the risk of nest abandonment and adult plover mortality (Neuman et al. 2004, Hardy and Colwell 2008, Dinsmore et al. 2014). Exclosures have been linked to lower adult survival rates (Gaines et al. 2020) and do not protect chicks from predation once the chicks leave the exclosure. The negative effects of exclosures also have been documented for other shorebird species (Isaksson et al. 2007, Barber et al. 2010). While using exclosures may provide benefits under certain circumstances (e.g., at times or in places with low raptor abundance), for a large part of the range of the plover population, the demographic costs associated with exclosures may outweigh the benefits (Eberhart-Phillips and Colwell 2014, Gaines et al. 2020).

Predator management techniques relying on behavioral modifications to predators (e.g., conditioned taste aversion, effigies) have been unsuccessful at minimizing predator impacts over the large spatio-temporal scales needed to improve plover reproductive success (Liebezeit and George 2002, Peterson and Colwell 2014, Brinkman et al. 2018) and thus have not been widely used.

Here we present a case study on raven impacts on plover nest hatching success. We also discuss current strategies and suggest several ways to improve management to increase plover numbers across the range. This case study relies on unpublished data sources and qualitative assessments from species experts rather than a rigorous experimental design and analysis. However, we believe that the information presented here provides a valuable overview and important regional perspectives on raven impacts and management practices.

Methods

We used 2 sources of information in compiling this case study on the impacts of ravens on plovers. We reviewed unpublished data and information from plover experts. We also reviewed data on population size from annual breeding window surveys (USFWS 2019) and from unpublished reports summarizing annual results at sites within each participating RU, including documentation of causes of nest failure. Breeding window surveys were conducted across the entire range of the listed population during a 1-week window of time in May to obtain a minimum estimate of the number of breeding plovers at current, historic, and potential breeding sites over time. Managers and volunteers have conducted these surveys since the 1990s. Breeding window surveys were conducted during non-migratory periods over a narrow time frame to minimize the chance of recounting birds moving between sites. Because all plovers are not detected on a single survey, window surveys provide an index of population size that is relatively consistent over time. Data from these window surveys were compiled in the USFWS 5-year review (USFWS 2019).

Figure 3. Common raven (*Corvus corax*; raven) tracks at a depredated western snowy plover (*Charadrius nivosus nivosus*) nest. Ravens tend to be messy around a nest site, sometimes digging into the nest bowl, walking around repeatedly, turning things over, or pecking at pieces of wood. They normally swallow eggs whole, so there is typically no evidence of the eggs (*photo courtesy of K. Castelein*).

Figure 4. Photo of a common raven (*Corvus corax*; raven) depredating a western snowy plover (*Charadrius nivosus nivosus*) nest in recovery unit 1. Ravens normally swallow eggs whole, as evidenced here (*photo courtesy of M. Lee*).

Methodologies for nest monitoring were similar among the sites for which we report nest monitoring data (e.g., Neuman et al. 2020). We monitored 1 or more times per week from the initiation of breeding (March or April) through the time that all broods fledged, typically by mid-September. We located nests using methods described by Page et al. (1985), finding nests by visually searching for incubating plovers, watching for plovers that were flushed off a nest, and following tracks.

We defined a nest as a nest bowl or scrape with eggs or tangible evidence of eggs in the bowl (i.e., eggshells). We predicted hatch dates by floating eggs (Westerskov 1950, Hays and LeCroy 1971). We monitored nests until they hatched or failed. We defined a hatched nest as a nest where at least 1 egg hatched and a failed nest as a nest where we found buried or abandoned eggs, infertile eggs, depredated eggs, signs of depredation (e.g., predator tracks or eggshell remains not typical of hatched eggs), or where eggs disappeared prior to the expected hatch date. If a failed nest was determined to be caused by predation, we determined the predator based on evidence at the nest including predator tracks (Figure 3), condition of the nest cup, and evidence from nest cameras (Figure 4). In places where nest failure due to ravens was widespread, we also attributed the failure of some "unknown fate" nests to ravens based on proximity and timing. The data we report here include sample sizes (number of nests monitored), hatch rate (percentage of nests that hatched 1 or more eggs), percentages of nest failure caused by predators, and percentages of nest failure caused by ravens.

In addition, researchers, land managers, and USFWS biologists from each participating RU summarized the current state of raven management, the barriers and constraints to improving management, and the best path forward for effective management. Most sites presented in this case study had predator management programs, and the use of these methods are described for each RU. Detailed descriptions of predator management techniques, equipment, and methods are in Hygnstrom et al. (1994). Below, we integrate these data sources and the information from experts to summarize the impacts of ravens on plovers, the state of predator management, and the resulting implications for

Table 1. Western snowy plover (*Charadrius nivosus nivosus;* plover) nests, nesting success, and nests depredated by common ravens (*Corvus corax*; ravens) throughout the plover range.

Recovery unit	Case study site(s)	Date range	Total nests with known fates	Total hatched nests (*n*)	Total hatched nests (%)	Total nests depredated by common ravens (*n*)	Total nests depredated by common ravens (% of all nests)	Total nests depredated by common ravens (% of failed nests)
1	Central Oregon coast[a]	2011–2020	4,765	1,956	41	294	6	10
2	Recovery unit 2[b]	2016–2020	417	147	35	68	16	25
3	Eden Landing Ecological Reserve[c]	2015–2016	186	79	42	40	22	37
4	Monterey Bay[d]	1984–2006	4,954	3,033	61	41	1	2
4	Monterey Bay[e]	2007–2019	5,098	2,896	57	486	10	22
4	Point Reyes National Seashore[f]	1996–2019	658	379	58	78	12	28
5	Vandenberg Space Force Base[f]	1994–2020	8,848	3,992	45	680	8	14
5	Oceano Dunes[d]	2003–2016	2,114	1,641	78	13	1	3
5	Oceano Dunes[e]	2017–2020	855	580	68	31	4	11
6	Marine Corps Base Camp Pendleton[a]	2006–2013	1,768	1,002	57	235	13	31
6	Marine Corps Base Camp Pendleton[g]	2017–2020	635	363	57	68	11	25

[a]Time period when nest exclosures were not used.
[b]Only reporting years where predator species was documented consistently.
[c]Only years with continuous camera monitoring to determine nest predators.
[d]Time period before increasing numbers of common ravens were present.
[e]Time period when increasing numbers of common ravens were present.
[f]All available data presented.
[g]Time period when nest exclosures were used.

future recovery of the plover population across the range of the listed population.

Results

Common raven impacts

Nest predation by ravens was reported across varying date ranges for each RU depending on available data. Some RUs report impacts dating back to the mid-1990s, and others report more recent impacts. The percentage of nests depredated by ravens varied from a low of 2% at Oceano Dunes (RU5) to a high of 22% at Eden Landing (RU3), with a rangewide average of 10% of all nests depredated by ravens. Raven predation was the cause of failure for 5% (Oceano Dunes) to 37% (Eden Landing) of all failed nests, with an average of 21% of all failed nests depredated (Table 1).

Common raven impacts by recovery unit

RU1. In RU1 (Washington and Oregon), plovers nest on exposed sandy beaches at 11 major sites and in smaller numbers at other sites along the coastline. The RU1 population has increased substantially in the past 2 decades due to collaborative management efforts between state and federal agencies (USFWS 2019; Figure 2). The recovery target for RU1 is 250 plovers; in 2019, 489 plovers were counted during the breeding season window survey (USFWS 2007, 2019).

The central Oregon coast population is among the most intensively monitored and managed populations on the Pacific coast, with higher levels of predator management than other sites, and this was reflected in the overall low rate of nest failure and failure attributed to ravens (Table 1). From 2009 to 2020, ravens were responsible for an average of 10% of all nest failures on the central coast of Oregon (n = 304; Table 1), the second lowest rate among the case studies. Nonlethal predator management has been conducted on the central coast of Oregon since 1991 and lethal predator management since 2002.

Predator management in Washington has also occurred on 3 beaches since 2013; raven impacts here are unknown. The RU1 area uses a wide variety of methods for predator management including nonlethal (e.g., hazing, marine mammal carcass and trash removal) and lethal (e.g., shooting, trapping, and DRC-1339). Exclosures have not been extensively used in RU1 since 2009, and the use of exclosures ceased completely in 2014.

RU2. In RU2, plovers have been recorded breeding at 23 sites (12 coastal beaches and 11 gravel river bars). The recovery target for RU2 (Del Norte, Humboldt, and Mendocino counties, California) is 150 breeding plovers (USFWS 2007). However, RU2 breeding plover numbers have never exceeded a high of 56 (USFWS 2019; Figure 2). Predation accounts for the highest percentage of identified nest failure every year, and in every year that predators were tracked (2016–2020) ravens were responsible for most predator-caused nest failure (Table 1).

In an 18-year study (2001–2018) of plover breeding activity in Humboldt County, the portion of RU2 with the most breeding sites, Colwell et al. (2019) reported a negative correlation between plover fledging success and raven activity. In 2020, only 11% of nests hatched, and ravens were responsible for 84% (n = 36 of 43) of all nest failure caused by predators. This was largely driven by a predation event during May and June at a single site with more than a dozen active breeding plover pairs (USFWS, unpublished data).

Despite the well-documented impacts of ravens in RU2, predator management has been limited to the use of nest exclosures at a few sites during 2000 to 2006 (13–28 nests per year) and 2010 (2 nests). Exclosure use was largely suspended in 2006 due to higher rates of nest abandonment, and adults nesting in exclosures were more vulnerable to predation, potentially impacting adult survival rates (Hardy and Colwell 2008, Eberhart-Phillips and Colwell 2014). Furthermore, the RU2 population is sustained by immigration from RU1, so there was additional concern that continued use of exclosures was encouraging plovers into a population sink (Eberhart-Phillips and Colwell 2014, Colwell et al. 2017).

RU3. In RU3 (San Francisco Bay estuary, California) plovers nest primarily at 6 major sites on tidally restricted, managed pond systems in the south bay. The breeding window survey in 2019 documented 190 adults in RU3 (USFWS 2019), which is well below the recovery target of 500 (USFWS 2007). Although there is substantial variability among years, breeding plover numbers in RU3 have stabilized in recent years due to improved habitat management and enhancement (USFWS 2019; Figure 2).

The unique habitat type in RU3 means that predators rarely leave a trace (i.e., no tracks left on hard-packed pond bottoms), and most depredated nests are attributed to unknown predators. However, using nest cameras, we documented ravens depredating plover nests in the 2015–2016 nesting seasons at the most densely populated breeding site within RU3 (Table 1). Ravens were responsible for 37% (n = 40 of 64) of all depredated nests and were the only confirmed nest predator caught on camera.

Lethal (e.g., trapping, shooting, predator nest removal) and nonlethal (e.g., hazing, perch removal and other habitat modifications) predator management occurs at most nesting sites in most years in RU3 but varies in scope depending on funding. Exclosures are not used due to the challenge of deploying them in the pond environment and concerns about reduced adult survival.

RU4. In RU4 (Sonoma, Marin, San Mateo, Santa Cruz and Monterey counties, California), there is 1 large (Monterey Bay) and 1 small (Point Reyes) plover population that nests on exposed sandy beaches and within 1 managed pond complex with occasional nesting at other beaches. The recovery target for RU4 is 400 plovers (USFWS 2007), and although RU4 numbers have increased since 1999, approaching the target several times in recent years, breeding plover numbers have decreased since 2017 (USFWS 2019, Neuman et al. 2021; Figure 2).

From 2016 to 2019, the RU4 population declined 17%, from 366 breeding adults in 2016 to only 303 in 2019 (USFWS 2019), and the population did not rebound in 2020 (Lau 2020, Neuman et al. 2021). Because Monterey Bay comprises >90% of the RU4 breeding population, the RU4 decline is mostly driven by population decline at this site where raven predation of plover nests has increased substantially over the period from 2007 to 2019, compared with years prior. At Point Reyes, population size also appears to be limited by low hatching success, with raven predation as the major identified cause of nest failure (Lau and Press 2019, Lau 2020, Lau et al. 2021). From 1996 to 2019 ravens caused 12% (n = 78 of 658) of all nests to fail and were responsible for 29% of all failed nests (Table 1). In 2019, ravens depredated 46% (n = 16 of 35) of all plover nests and were responsible for 70% (n = 16 of 23) of nests that failed (Lau and Press 2019).

In Monterey Bay prior to 2007, ravens were not a predator of plover nests. From 1984 to 2006, ravens caused 1% of all nest failures and were responsible for 2% of all failed nests (Table 1). Beginning in 2007, raven predation of plover nests became more widespread. From 2007 to 2019, ravens caused 10% of all nest failures and were the cause of loss of 22% of all failed nests (Table 1).

Predator management in RU4 includes hazing, lethal removal (e.g., shooting, trapping, DRC-1339), and occasional use of individual nest exclosures. At Point Reyes, nest exclosures are the only predator management method used.

RU5. The RU5 area (San Luis Obispo, Santa Barbara, and Ventura counties, California) is the largest recovery unit, with a recovery target of 1,200 breeding plovers (USFWS 2007). The RU5 area came closest to this target in 2015, when 963 breeding plovers were counted (USFWS 2007, 2019; Figure 2). By the 2020 breeding season, this number had dropped to 861 breeding adults (USFWS, unpublished data).

Predation is the primary cause of nest failure throughout RU5, and ravens are among the most common nest predators. In 2020, 8 of 16 sites reported ravens as a primary source of nest predation, and ravens are now affecting an increasing number of sites where they had not previously been a primary nest predator (USFWS, unpublished data). In Morro Bay, ravens were not commonly documented nest predators until 2019 and 2020, when 4% and 10% of depredated nests were taken by ravens and 29% and 32% of depredated nests were taken by either ravens or American crows (*C. brachyrhynchos*; California Department of Parks and Recreation [CDPR] 2019*a*, 2020).

Similarly, at Oceano Dunes State Vehicular Recreation Area, prior to 2017, sightings of ravens and nest failure caused by ravens were rare (CDPR 2019*b*). Oceano Dunes is among the most intensively managed plover nesting sites on the Pacific coast, with comparatively higher levels of predator management than other sites and thus typically a low rate of nest failure to predators. From 2002 to 2016, an average of only 7% of nests failed due to predation, with only 11 nest failures during this time caused by ravens. However, from 2017 to 2020, this overall rate of nest failure due to predation increased to an average of 15%, with ravens responsible for 13–28% of nest depredations each year, driving the overall rate of nest failure to predators (CDPR 2020).

In contrast to Morro Bay and Oceano Dunes, where raven predation is a relatively new phenomenon, at Vandenberg Space Force Base, ravens have caused variable levels of plover nest loss in most years since at least 1994 (when monitoring began), ranging from 1–61% of predator losses or an average of 25 nests each year. In that time frame, an overall 14% of known nest failure has been caused by ravens (Table 1). Peaks in predation occurred in 2003 and 2004, when 63 and 66 nests were depredated, and in 2011, when 73 nest failures were attributed to ravens. The most recent peak in raven predation of plover nests was from 2017 to 2019, when 118, 48, and 43 nest failures were caused by ravens, respectively (Robinette et al. 2019).

Predator management at most sites in RU5 includes both nonlethal methods (e.g., hazing, nest exclosures, fencing, trash management) and lethal methods (e.g., predator nest removal, predator trapping and relocation, shooting, and DRC-1339). In 2020, 10 of 16 nesting sites in RU5 had predator management programs in operation. Sites with more funding spent on predator management (i.e., Oceano Dunes) had lower levels of nest predation.

RU6. The RU6 area (Los Angeles, Orange, and San Diego counties, California) includes some of the most urbanized plover nesting sites in the range of the listed population. The RU6 recovery target is 500 breeding plovers. The RU6 area has approached but not achieved this goal in recent years (USFWS 2007, 2019; Figure 2). Brinkman et al. (2018) reported that ravens were limiting plover nest success in RU6.

At Marine Corps Camp Pendleton, ravens were the cause of 31% (n = 235 of 766) of all nest failure due to predation; even with the use of nest exclosures in more recent years, ravens were still responsible for 25% (n = 68 of 272; Table 1) of all nest failure due to predation. The RU6 area uses a wide variety of tools for predator management, including hazing, lethal removal, nest exclosures, and DRC-1339. It uses exclosures more commonly than any of the other recovery units, with little apparent impacts to adult plovers (S. Vissman, U.S. Fish and Wildlife Service, personal communication).

Discussion

The negative impact of ravens on plover nesting success adds to the suite of pressures on this threatened subspecies. The Pacific coast population has not met recovery population targets, and we believe that the evidence presented here demonstrates that raven predation of plover nests is becoming more widespread and common and is a contributing factor.

Ravens are one of the most common predators identified at most plover nesting sites. They are highly efficient predators that range over large distances (Rösner and Selva 2005), allowing them to depredate plover nests across a large area within a span of a few days. After predation events have occurred, many plovers lay replacement clutches. This widespread renesting can result in synchronous hatching, which may increase the susceptibility of nests and chicks to density-dependent impacts from predators (Page et al. 1983) and to extreme weather events related to climate change, such as high tides and storms (Neuman et al. 2019, 2020).

Plovers may respond to predation pressure by dispersing to other breeding sites, which can be adaptive if the alternative sites have lower predation pressure (Pearson and Colwell 2013). For example, in RU4, intense predation pressure from ravens probably has been an important factor causing within- and among-season movements ranging from local (1–5 km) to regional (10–30 km) scales (Point Blue, unpublished data). In the Monterey Bay area, raven predation pressure over many years is probably the primary factor causing the near-extirpation of breeding at 4 northern Santa Cruz County beaches by 2008; some plovers subsequently moved >30 km south to nest in areas with lower predation pressure (Point Blue, unpublished data).

At Point Reyes in 1989, after most nests were depredated by ravens, plovers moved within the nesting season from Point Reyes Great Beach to a site with lower predation pressure, Salmon Creek Beach, a distance of >20 km (Point Blue, unpublished data). With raven populations expanding in RU4, few low-pressure sites remain (Lau 2020, Neuman et al. 2021, Lau et al. 2021), and it is unclear if these documented small-scale or larger-scale movements have conferred any fitness advantages in the long-term.

Habitat restoration, when combined with predator management, has a positive effect on plover nest success (Dinsmore et al. 2014). However, the benefits of habitat restoration may diminish over time if there is no predator management. In RU2, plovers experienced substantial nest success for 4 consecutive years at a restored nesting site until the 2020 breeding season when predation from ravens increased significantly (USFWS, unpublished data). In RU4, plover nest success and occupancy at restored sites has declined over time, possibly due to raven predation pressure (Lau and Press 2019, Lau 2020). Given the high cost of habitat restoration, managers must consider that benefits to plovers may not persist without annual predator management.

Constraints

Site-specific constraints to managing predators exist, but there also are consistent themes that emerge across multiple RUs. Policy, planning, and permitting constraints are governed by state and federal agencies, as well as local land managers, and are influenced by public opinion. In addition, there are specific limitations to managing species as intelligent and adaptable as ravens. These limitations include technical challenges related to the availability of new tools as ravens learn, practical constraints imposed by local landscape-related factors, and the challenge of addressing landscape-level anthropogenic subsidies that are driving raven population increases at a larger scale. Finally, and perhaps most importantly, there are significant limits to the funding that is currently available for plover conservation actions, including predator management.

Most RUs use a variety of methods, from hazing to nest exclosures, to lethal removal, to control ravens, and are constantly working to improve the success of these methods, innovate new methods, and reduce costs. But while RU1 has used these methods to meet and exceed the population goals laid out in the recovery plan, these same methods are proving inadequate in other RUs. In RU4, for example, shooting has been a primary means of lethal control, but this method has been less successful over time as ravens learn to avoid areas when managers are present. Evidence from captive studies suggests that ravens recognize and learn to avoid specific humans they view as dangerous (Blum et al. 2020), which may affect the efficacy of methods such as shooting or baiting with DRC-1339 as ravens learn avoidance behaviors.

Predator management implementation success in many areas is affected by the physical constraints of the local landscape. In more than half of the RUs (RU1, RU3, RU4, RU5, RU6), many plover nesting sites are adjacent to public trails and beaches. This is often not compatible with lethal control of predators because of high public visibility or risk to humans. In some cases (RU3, RU4), adjacent private landowners allow predator control on their lands, but these agreements can be difficult to maintain due to the lack of common goals among private and public landowners. The de facto result is that predator control occurs along narrow swaths of habitats where ravens are spending relatively little time before departing back to adjacent areas where control is not feasible.

Adding to the implementation problems posed by adjacent lands are the subsidies provided to ravens, including food (e.g., garbage, agricultural and ranching products), water, and nesting sites (power towers, landscaping trees), which are driving raven population increases (Liebezeit and George 2002). Land uses that generate subsidies include agriculture (RU4, RU5), ranching (RU1, RU2, RU4), housing and other developments (RU3, RU4, RU5, RU6), landfills (RU3, RU4, RU5, RU6), and campgrounds and high-use visitor areas (all RUs).

Funding is a significant constraint on the type and intensity of predator management that can be implemented in every RU. Most nesting sites are in public ownership, and the land managers' ability to secure funding is variable. At sites with regulatory requirements to protect plovers, annual funding is more secure (e.g., Oregon Parks and Recreation Department's Habitat Management Plan in RU1, Oceano Dunes State Vehicular Recreation Area in RU5, military installations in RU5 and RU6), and these sites tend to be the most effective at reducing the amount of predation on plover nests. Where these regulatory requirements are lacking, funding must be carved from dwindling state and federal operating budgets, special funds, or from strategically coordinated grant sources.

Management implications

Successful predator management requires a wide variety of tools, long-term commitments to funding, and coordinated outreach to adjacent landowners and the public to enable management efforts. Our case study documents that ravens are a significant limiting factor and that improved management will be necessary to mitigate the decreasing efficacy of predator management methods and an increasing raven population. One tool, DRC-1339, is an important tool in raven management but has not been approved for use in all RUs. Multi-state or multi-county regulatory approval of DRC-1339 would allow more widespread use of this tool. In addition, new nonlethal methods and other lethal trapping methods (more widespread use of lures, bait, calls, etc.) have all been identified as important raven management needs.

For plover populations to reach recovery targets, we need landscape-scale management to address anthropogenic subsidies, streamlined and flexible permitting for predator management techniques, new on-the-ground techniques to address intelligent and adaptable predators, and more funding. Without consistent predator management, impaired breeding success across the range of the Pacific coast population of the plover will continue to be a barrier to recovery.

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Literature cited

Barber, C., A. Nowak, K. Tulk, and L. Thomas 2010. Predator exclosures enhance reproductive success but increase adult mortality of piping plovers (*Charadrius melodus*). Avian Conservation and Ecology 5(2):6.

Blum, C. R., W. Tecumseh Fitch, and T. Bugnyar. 2020. Rapid learning and long-term memory for dangerous humans in ravens (*Corvus corax*). Frontiers in Psychology 11:581794.

Brinkman, M. P., D. K. Garcelon, and M. A. Colwell. 2018. Evaluating the efficacy of carbachol at reducing corvid predation on artificial nests. Wildlife Society Bulletin 42:84–93.

Burrell, N. S., and M. A. Colwell. 2012. Direct and indirect evidence that productivity of snowy plovers *Charadrius nivosus* varies with occurrence of a nest predator. Wildfowl 62:204–223.

California Department of Parks and Recreation (CDPR). 2019*a*. Annual report for the western snowy plover in the San Luis Coast District in 2019. California Department of Parks and Recreation, Sacramento, California, USA.

California Department of Parks and Recreation (CDPR). 2019*b*. Nesting of the California least tern and western snowy plover at the Oceano Dunes State Vehicular Recreation Area, San Luis Obispo County, California, 2019 season. California Department of Parks and Recreation, Off-Highway Motor Vehicular Recreation Division, Sacramento, California, USA.

California Department of Parks and Recreation (CDPR). 2020. Nesting of the California least tern and western snowy plover at the Oceano Dunes State Vehicular Recreation Area, San Luis Obispo County, California, 2020 season. California Department of Parks and Recreation, Off-Highway Motor Vehicular Recreation Division, Sacramento, California, USA.

Colwell, M. A., E. J. Feucht, M. J. Lau, D. J. Orluck, S. E. McAllister, and A. N. Transou. 2017. Recent snowy plover population increase arises from high immigration rate in coastal northern California. Wader Study 124:40–48.

Colwell, M. A., M. J. Lau, E. J. Feucht, and J. J. Pohlman. 2019. Corvids and humans create ecological traps in otherwise suitable snowy plover habitat. Wader Study 126:116–124.

Colwell, M. A., C. B. Millett, J. J. Meyer, J. N. Hall, S. J. Hurley, S. E. McAllister, A. N. Transou, and R. R. LeValley. 2005. Snowy plover reproductive success in beach and river habitats. Journal of Field Ornithology 76:373–382.

Demers, S. A., and C. W. Robinson-Nilsen. 2012. Monitoring western snowy plover nests with remote surveillance systems in San Francisco Bay, California. Journal of Fish and Wildlife Management 3:123–132.

Dinsmore, S. J., E. P. Gaines, S. F. Pearson, D. J. Lauten, and K. A. Castelein. 2017. Factors affecting snowy plover chick survival in a managed population. Condor 119:34–43.

Dinsmore, S. J., D. J. Lauten, K. A. Castelein, E. P. Gaines, and M. A. Stern. 2014. Predator exclosures, predator removal, and habitat improvement increase nest success of snowy plovers in Oregon, USA. Condor 116:619–628.

Eberhart-Phillips, L., and M. Colwell. 2014. Conservation challenges of a sink: the viability of an isolated population of the snowy plover. Bird Conservation International 24:327–341.

Eberhart-Phillips, L. J., B. R. Hudgens, and M. A. Colwell. 2016. Spatial synchrony of a threatened shorebird: regional roles of climate, dispersal and management. Bird Conservation International 1:119–135.

Gaines, E. P., S. J. Dinsmore, and M. T. Murphy. 2020. Effects of management for productivity on adult survival of snowy plovers. Journal of Field Ornithology 91:130–141.

Hardy, M. A., and M. A. Colwell. 2008. The impact of predator exclosures on snowy plover nesting success: a seven-year study. Wader Study Group Bulletin 115:161–166.

Hays, H., and M. LeCroy. 1971. Field criteria for determining incubation stage in eggs of the common tern. Wilson Bulletin 83:425–429.

Hygnstrom, S. E., R. M. Timm, and G. E. Larson, editors. 1994. Prevention and control of wildlife damage. University of Nebraska-Lincoln, Lincoln, Nebraska, USA.

Isaksson, D., J. Wallander, and M. Larsson. 2007. Managing predation on ground-nesting birds: the effectiveness of nest exclosures. Biological Conservation 26:136–142.

Lau, M. 2020. Breeding western snowy plover monitoring at Point Reyes National Seashore, Marin County, California, 2020 annual report. Natural Resource Report, NPS/SFAN/ NRR, National Park Service, Fort Collins, Colorado, USA.

Lau, M. J., B. H. Becker, and D. T. Press. 2021. Common raven impacts on the productivity of a small breeding population of snowy plovers. Human–Wildlife Interactions 15:391–404.

Lau, M., and D. Press. 2019. Point Reyes National Seashore western snowy plover breeding summary 2019. National Park Service, Fort Collins, Colorado, USA.

Liebezeit, J. R., and T. L. George. 2002. A summary of predation by corvids on threatened and endangered species in California and management recommendations to reduce corvid predation. California Department of Fish and Game, Species Conservation and Recovery Program Report 2002-02, Sacramento, California, USA.

Neuman, K. K., G. W. Page, L. E. Stenzel, J. C. Warriner, and J. S. Warriner. 2004. Effect of mammalian predator management on snowy plover breeding success. Waterbirds 27:257–263.

Neuman, K. K., R. W. Stein, C. R. Eyster, and T. Gardali. 2019. Climate-smart conservation of beaches and dunes for western snowy plover recovery in Monterey Bay, California. Point Blue Conservation Science, Contribution #2301, Petaluma, California, USA.

Neuman, K., L. Stenzel, C. Eyster, B. Barbaree, E. Haile, D. Dixon, C. Hickey, and A. Palkovic. 2021. Reproductive success and breeding population size of snowy plovers in the Monterey Bay region, 2020. Point Blue Conservation Science, Petaluma, California, USA.

Neuman, K., L. Stenzel, C. Eyster, B. Barbaree, E. Haile, D. Dixon, J. C. Warriner, C. Hickey, and A. Palkovic. 2020. Reproductive success and breeding population size of snowy plovers in the Monterey Bay region, 2019. Point Blue Conservation Science, Petaluma, California, USA.

Page, G. W., and L. E. Stenzel. 1981. The breeding status of the snowy plover in California. Western Birds 12:1–40.

Page, G. W., L. E. Stenzel, and C. A. Ribic. 1985. Nest site selection and clutch predation in the snowy plover. Auk 102:347–353.

Page, G. W., L. E. Stenzel, W. D. Shuford, and C. R. Bruce. 1991. Distribution and abundance of the snowy plover on its western North American breeding grounds. Journal of Field Ornithology 62:245–255.

Page, G. W., L. E. Stenzel, D. W. Winkler, and C. W. Swarth. 1983. Spacing out at Mono Lake: breeding success, nest density, and predation in the snowy plover. Auk 100:13–24.

Pearson, W. J., and M. A. Colwell. 2013. Effects of nest success and mate fidelity on breeding dispersal in a population of snowy plovers *Charadrius nivosus*. Bird Conservation International 24:342–353.

Peery, M. Z., and R. W. Henry. 2010. Recovering marbled murrelets via corvid management: a population viability analysis approach. Biological Conservation 143:2414–2424.

Peterson, S. A., and M. A. Colwell. 2014. Experimental evidence that scare tactics and effigies reduce corvid occurrence. Northwest Naturalist 95:103–112.

Rinkert, A. 2018. Santa Cruz County breeding bird atlas II, year 2 annual report. Santa Cruz Bird Club, Santa Cruz, California, USA, <https://santacruzbirdclub.org/wp-content/uploads/2019/09/AtlasYear2_AnnualReport.pdf>. Accessed March 10, 2021.

Roberson, D., and C. Tenney, and R. Carratello, editors. 1993. Atlas of the breeding birds of Monterey County. Monterey Peninsula Audubon Society, Monterey, California, USA.

Robinette, D. P, R. Butala, E. L. Rice, J. K. Miller, L. A. Hargett, and J. Howar. 2019. Monitoring and management of the endangered California least tern and the threatened western snowy plover at Vandenberg Air Force Base, 2019. Contribution no. 2270, Point Blue Conservation Science, Petaluma, California, USA.

Rösner, S., and N. Selva. 2005. Use of the bait-marking method to estimate the territory size of scavenging birds: a case study on ravens (*Corvus corax*). Wildlife Biology 11:183–191.

Sauer, J. R., D. K. Niven, J. E. Hines, D. J. Ziolkowski, Jr., K. L. Pardieck, J. E. Fallon, and W. A. Link. 2017. The North American breeding bird survey, results and analysis 1966–2015. Version 2.07.2017. U.S. Geological Survey, Patuxent Wildlife Research Center, Laurel, Maryland, USA.

Smith, R. K., A. S. Pullin, G. B. Stewart, and W. J. Sutherland. 2010. Effectiveness of predator removal for enhancing bird populations. Conservation Biology 24:820–829.

U.S. Fish and Wildlife Service (USFWS). 1993. Endangered and threatened wildlife and plants: determination of threatened status for the Pacific coast population of the western snowy plover; final rule. Federal Register 58:12864–12874.

U.S. Fish and Wildlife Service (USFWS). 2007. Recovery plan for the Pacific coast population of the western snowy plover (*Charadrius alexandrinus nivosus*). U.S. Fish and Wildlife Service, Sacramento, California, USA.

U.S. Fish and Wildlife Service (USFWS). 2019. 5-year review for the Pacific coast population of the western snowy plover (*Charadrius alexandrinus nivosus*). Arcata Fish and Wildlife Office, Arcata, California, USA.

Westerskov, K. 1950. Methods for determining the age of game bird eggs. Journal of Wildlife Management 14:56–67.

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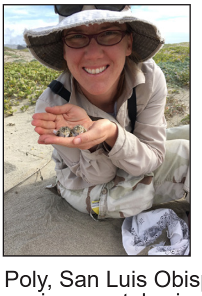

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