# Oyster Shell Habitat Enhancement for Breeding Snowy Plovers in Pond E14, Eden Landing Ecological Reserve, 2015

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**LIST OF FIGURES**

**LIST OF TABLES**

**SUMMARY**

The San Francisco Bay Bird Observatory (SFBBO), Don Edwards San Francisco Bay National Wildlife Refuge (Refuge), California Department of Fish and Wildlife (CDFW), Hayward Area Recreation and Park District (HARD), and East Bay Regional Park District (EBRPD) form the Western Snowy Plover (*Charadrius nivosus nivosus*) Recovery Unit 3. The goal of this collaboration is to survey managed ponds and other habitats for Western Snowy Plovers, track breeding success, and contribute to the management and recovery of this species in the San Francisco Bay.

From 2008 to 2014, SFBBO conducted a pilot study investigating the effects of oyster shell habitat enhancement on Snowy Plover nesting success. One hectare test plots were distributed on salt pond bottoms in Eden Landing Ecological Reserve (Eden Landing), Hayward, California. Data from this pilot study indicated that oyster shells may provide beneficial cover for nesting Snowy Plovers and suggest further breeding benefits on a larger scale. In October 2014 and through funding from Ducks Unlimited, two large oyster shell enhancement plots (New 1, New 2) were distributed in pond E14, Eden Landing; non-shelled areas acted as controls. During the 2015 breeding season, SFBBO monitored Snowy Plover adults, nests, chicks, predatory species and activity, and biotic and abiotic soil characteristics of all areas within E14.

Our results from 2015 show that large scale oyster shell enhancement increased breeding bird numbers, nesting density, and apparent chick fledge rates compared to previous seasons. We counted an average of 80 breeding Snowy Plovers per week in pond E14. Over the course of the breeding season (March-September), we documented a total of 98 nests; 50 in New 1, 28 in New 2, and 20 in control areas. In E14, we determined the fate of all known nests and found that apparent nest success (defined as the percentage of nests that successfully hatched at least one egg out of the total nests monitored) was 60%. Nest success rates by treatment area were 70% in New 1, 43% in New 2, and 60% in control areas. Remaining nests failed due to predation (32%), abandonment (7%), and for unknown reasons (1%). Snowy Plovers selected enhanced areas for nest locations and nest density was consequently higher there, particularly in New 1. We banded 59 Snowy Plover chicks in E14, and our apparent fledge success rate was 44% (defined as a chick surviving to 31 days post-hatching).

Our statistical models however, show that enhancement had no significant effect on nest survival, chick behavior during development, biotic or abiotic characteristics in E14. We caution that many of our models have low power due to small sample sizes, and we *strongly* recommend the continuation of this monitoring effort for an additional year. This will not only strengthen our current analyses, it will also allow for additional analyses to investigate possible relationships between Snowy Plover fledge success and oyster shell enhancement. Monitoring during the 2016 season will also allow us to document whether Snowy Plovers follow similar nesting patterns of decreasing use of enhanced areas over time. These findings will ultimately inform species and Project management, and will impact the targeted use of available resources.

## INTRODUCTION

The Pacific Coast population of the Western Snowy Plover (*Charadrius nivosus nivosus*, Snowy Plover) breeds on coastal sandy beaches and is behaviorally distinct from the interior population (Funk 2006). Snowy Plovers have also moved away from their primary coastal range and into the South San Francisco Bay (South Bay), taking advantage of dry salt panne habitat provided by former salt evaporation ponds. The Pacific Coast population of Snowy Plovers has declined as a result of poor reproductive success, due to habitat loss or alteration, human disturbance, and increasing predation pressure (Page et al. 1991, USFWS 2007). In response to this decline, the U.S. Fish and Wildlife Service (USFWS) listed the Pacific Coast population of the Western Snowy Plover population as federally threatened in 1993 (USFWS 1993). They are listed as a species of special concern in California (CDFW).

Snowy Plovers in the South Bay nest almost exclusively on salt pond habitat. In 1992, the Don Edwards San Francisco Bay National Wildlife Refuge (Refuge) began surveying for breeding Snowy Plovers on Refuge lands in the South Bay, and was later joined by the California Department of Fish and Wildlife (CDFW) in 2000 to survey for breeding Snowy Plovers in Eden Landing Ecological Reserve (Eden Landing). The San Francisco Bay Bird Observatory (SFBBO) and the Refuge have been jointly monitoring breeding plovers since 2003.

The South Bay Salt Pond Restoration Project (the Project) plans to restore 15,100 acres of former salt production ponds in the South Bay to tidal marsh and managed ponds. The Project's actions would ultimately result in the loss of potential Snowy Plover breeding habitat (dry salt ponds). Regardless, the Project has set a management target of maintaining 250 breeding individual Snowy Plovers within its footprint (USFWS and CDFW 2007), which echoes the federal species' Recovery Goal of maintaining 500 breeding individuals in the South Bay (USFWS 2007). To aid in achieving the Project goal, SFBBO and the Refuge began investigating methods of habitat enhancement in order to maximize breeding success in the remaining potential breeding habitat.

Predation is consistently the leading factor limiting Snowy Plover nesting success in the South Bay (Tokatlian et al. 2014). There is evidence that adding material (oyster shell, wood chips) to nesting substrate may positively influence nest site selection and increase hatching success of breeding shorebirds (Zarnetske et al. 2010). Pacific oyster shells are similar to Snowy Plovers in shape and color, and may provide improved camouflage for nesting adults, eggs, and chicks. Oyster shells have been spread in a number of coastal breeding locations, including Oregon, Washington and Louisiana (Pearson et al. 2009), and monitoring results from these areas showed that Snowy Plovers nested almost exclusively in the shelled areas in subsequent years. Researchers in Hayward, California also found that Snowy Plover nest sites were selected in areas with increased oyster shell cover compared to control sites (Riensche et al. 2015).

SFBBO ran a pilot study from 2008 to 2014 which investigated the effects of oyster shell enhancement on Snowy Plover nesting success (Tokatlian et al. 2014). From 2008 to 2010, a total of 15 blocks were placed in four Eden Landing salt ponds using a randomized block design; selected ponds were previously managed for Snowy Plovers. Each study plot consisted of one

1-ha oyster shell treatment plot (shells spread at 5-8 shells/ $m^2$ on dry pond bottom) and a corresponding 1-ha control plot (untreated dry pond bottom). Study plots were then monitored from 2009 to 2014. Oyster shells used for this project were donated by Drake's Bay Oyster Farm. SFBBO staff, volunteers, and the California Conservation Corps spread the shells by hand.

During our pilot study we consistently documented higher apparent nest densities in the 1-ha shell plots compared to other, corresponding untreated control plots (Tokatlian et al. 2014). Conversely, apparent depredation rates tended to be higher in control plots which supports our hypothesis that oyster shell enhancement provides more opportunities for Snowy Plovers to evade detection from predators. These results suggest that oyster shell habitat enhancement, if applied over larger areas, may have positive impacts on reproductive success and could be an important part of the strategy to meet Recovery Unit 3 goals and management targets for this federally threatened species. Since dry panne habitat elsewhere in the Bay Area will decrease due to restoration and other activities, enhancements that show the potential to improve the number and success of nests in remaining habitat are valuable.

With support from the findings from our 2008-2014 pilot study, SFBBO and CDFW initiated a large-scale oyster shell habitat enhancement project at pond E14, Eden Landing. In September of 2014, Ducks Unlimited and contracted crews treated a total of 20.2 hectares of dry pond bottom with oyster shells at the previously tested density (5-8 shells/ $m^2$), representing approximately a third of the surface area of E14. The remaining two-thirds of E14 were left as untreated controls. We designed a spatial configuration in which the shell blocks alternated with the control blocks in order to avoid clustering treatments in one region of the pond, as well as to address pre-existing variation in habitat quality for breeding Snowy Plovers. Two distinct plots were created – a western plot totaling 6.47 hectares and an eastern plot totaling 13.76 hectares. To further limit predation pressure, seven hunting blinds and several perches within the pond were also removed before the start of the 2015 breeding season; historical structures within the pond that could not be removed were treated with Nixalite.

We hypothesize that large scale oyster shell enhancement will increase both nest and Snowy Plover chick survival through improved camouflage, and will reduce detectability of all plovers by predators. If proven effective, large scale enhancement may be used throughout the Project footprint in order to offset negative impacts to Snowy Plovers as potential breeding habitat continues to be lost. If however this application fails to prevent heavy predation on chicks, or perhaps has a negative impact on chick survival (potentially due to changes in the invertebrate prey), the overall contribution of the enhancement to plover recovery may be negligible. Consequently, it would be difficult to justify large scale adoption of this approach. Here we discuss our monitoring methods and results of the first year of large scale enhancement in pond E14.

## METHODS

### Study Area

Pond E14 is located in Eden Landing Ecological Reserve (Eden Landing), Hayward, California (Figure 2) and is approximately 67 hectares in size. Eden Landing (formerly known as Baumberg) is owned and managed by CDFW, and includes approximately 2,590 hectares of former salt ponds, marsh, and tidal habitat. Pond E14 is the southernmost salt evaporation pond in a three pond system; one of five major pond systems in the complex. Three salt ponds south of pond E14 were breached in 2011 as part of the Project's restoration activities and have since been open to tidal action (Figure 2).

A total of 20.2 hectares of oyster shells were spread on the dry E14 pond bottom which represents approximately one third of its surface area. The remaining two-thirds of the pond were left as untreated controls. Two distinct plots were created – a western plot totaling 6.47 hectares (and including three 1-ha test plots is termed New 1 for this report) and an eastern plot totaling 13.76 hectares (termed New 2 for this report; Figure 3).

### Snowy Plover Surveys

Snowy Plovers in the San Francisco Bay nest predominantly on dry pond bottoms, berms, and levees. To document areas used by Snowy Plovers and to estimate the number of Snowy Plovers in pond E14, we applied our standard survey methods used throughout the South Bay. From March 1 to August 31, 2015, SFBBO staff biologists surveyed pond E14 weekly by driving slowly on the perimeter levee. We stopped approximately every 0.3 miles to scan for Snowy Plovers with spotting scopes. During each survey, we recorded the number and behavior of all Snowy Plovers present, identified the sex and age class of each individual using plumage characteristics (Page et al. 1991), and marked the approximate location of sightings on a geo-referenced map. We also recorded the color-band status, and combination of any banded plover sighted.

### Nesting Monitoring

Nests were located during weekly observational surveys by identifying incubating females through scopes and binoculars. We then searched for nests on foot and recorded nest locations with a GPS unit (Garmin® GPS 60 or Garmin® eTrex Venture HC). Occasionally, undetected new nests were found while walking on the pond bottom in search of previously detected nests.

We monitored nests weekly until we determined the fate of each nest. On each visit, we recorded whether the nest was still active (eggs present and adults incubating), and the number of eggs or chicks in the nest. Eggs were floated (Hays and LeCroy 1971) to estimate egg age. Snowy Plover nests are active for an average of 33 days, from initiation (the date the first egg was laid) to hatching (Warriner et al. 1986). Using the known egg age from float information, we calculated the nest initiation date and predicted hatch date for all nests monitored. When there were no longer eggs in the nest, we assigned each nest a fate based on evidence seen at the nest (Mabee 1997). Nest fates included: hatched, depredated, abandoned, and unknown. Each nest was designated a habitat type of New 1 (specifically pilot study plots or large scale plot, New 2, or Control to reflect the treatment type depending on geographic location within the pond.

**Brood and Brood Behavior**

Broods (any observed chicks and their respective adults) were monitored during observational surveys, conducted once a week and once every other week throughout the season. Information from every detected brood was recorded including time, location and treatment type, behavior, chick age, and band information. Brood surveys were done independently from nest surveys, but on the same day, in order to maximize the amount of monitoring time during optimum visibility conditions.

Brood behavior was monitored during observational surveys, conducted at the same frequency and in concurrence with regular brood surveys. Four broods were selected and observed for twenty minutes, and the behavior of the adult and one chick was recorded at 30 second intervals. The number of adult foraging pecks was also counted every five minutes for 30 seconds and was used as an observational indicator of foraging rates and possibly variation in prey availability (Rose and Nol 2010).

**Fledging Success**

SFBBO biologists banded Snowy Plover chicks in E14 in order to study their movement across treatment areas and to estimate fledging success rates. Due to logistical and resource limitations, only a sample of birds were banded in E14. We followed standard banding techniques and began by checking nests daily, starting four days before the estimated hatch date. Chicks leave the nest site within a few hours after hatching due to their precocial nature. Banders arrived at nest sites within this timeframe in order to allow chicks time to, and before permanently leaving their nest. We banded each chick with a unique four-color combination by placing two bands on each leg below the tibiotarsal joint. Each combination consisted of three darvic or acetal color bands and one silver USFWS band which was wrapped in colored auto pin-striping tape.

We defined a fledged chick as one that survived to 31 days of age, and at which point are considered to be flight capable (Warriner et al. 1986). We calculated apparent fledging success as the percentage of banded chicks that reached fledge age out of the total number of banded chicks. We note that this method of estimating fledging success has limitations due to salt pond habitat characteristics, and therefore advise caution when considering apparent fledge rates (see *Discussion* for further explanation).

**Habitat Characteristics**

A total of 40 sample points were randomly generated to collect soil quality and invertebrate data within pond E14. Points were generated in ArcMap using a 10m minimum distance value. Fifteen points were generated in New and Control plots (respectively) and ten points were generated in the Old pilot study shell plots. Higher plot numbers in New and Control reflect the larger treatment areas relative to Old shell treatment plots. We chose to sample the Old 1-ha pilot study plots to investigate whether oyster shell enhancement had any long term impacts to biotic and abiotic soil characteristics.

*Soil Quality*

Half of the points in each treatment type were sampled every other week in order to minimize disturbance to breeding Snowy Plovers; all points were sampled once a month. Soil moisture and temperature readings were taken in the field using a Vegetronix VG-meter 200 handheld soil moisture device. The probe was inserted completely and parallel to the ground approximately one inch below the surface to obtain an accurate reading. Soil samples were collected using a 6cm PVC core (Rose and Nol 2010) with non-beveled edges, placed in individual plastic bags, and labeled by collection site.

Soil samples were then taken to the Refuge's Environmental Education Center (EEC) in Alviso for processing (Carter and Gregorich 2006; Walworth 2011; ASTM International 2015). The sample mass was weighed within a few hours of collection in order to provide the wet weight of the sample. Samples were then plated and stored onsite, and allowed to air dry for 12-18 hours. After drying, each sample was weighed again to obtain the dried weight and was then passed through a 0.8mm metal sieve (Rose and Nol 2010) which filtered out larger particles that might obfuscate meter readings. Forty grams of the sieved sample soil was prepared with 200mL of deionized water (1:5 dilution ratio), mixed frequently for one hour, and allowed to sit undisturbed for 30 minutes prior to pH and salinity measurements. This process was repeated for all soil samples collected the previous day.

A YSI 85 Meter (YSI Incorporated, Yellow Springs Ohio) was used to measure the pH of each sample. Once calibrated, the sonde was placed ½ inch above the settled soil and allowed to stabilize prior to recording a reading. After a pH measurement was recorded, the probe was then rinsed with water and dried. The process was then repeated for all soil samples prepared that day. Following pH analysis, the salinity of each sample was measured using a handheld refractometer. Samples were filtered using a 10ml syringe and 0.45um pore filter to remove any remaining particles. The salinity of the filtered solution was then measured using the refractometer, as a percentage. Once the salinity measurement was recorded, the refractometer lens and syringe filter were rinsed with deionized water and dried before the next sample was analyzed. This process was completed for all soil samples prepared that day.

*Invertebrate Abundance and Density*

Invertebrate data were collected at eight of the 15 sample points in New and Control plots, and four of the 10 sample points in Old shell plots. Points were sampled at the same frequency as soil quality data. Invertebrates were collected with sticky traps using the method outlined by Anteau and Sherfy (2010). Two paint sticks were coated with Tanglefoot insect glue (The Tanglefoot Company, Grand Rapids, MI), with one placed horizontal to the ground and another placed vertically. The sticks were covered with chicken-wire cages (ht = 0.6m, diam = 0.5m, mesh size = 2.5cm; LeFer et al. 2008). Cages were used to prevent Snowy Plover adults, chicks, or other sensitive species from becoming entangled. Sticks were left out for three hours, after which they were wrapped in plastic wrap and stored in a freezer until analysis (Anteau and Sherfy 2010).

Sticks were analyzed under a dissecting scope. Invertebrates were identified to species when possible or to the nearest taxonomic level, and measured to within 0.5mm. The abundance of invertebrates was calculated by counting the total number of invertebrates on the horizontal and vertical sticks for each sample site. The length of all invertebrates were averaged by stick and then by each sample site, with zeros removed. Most of the collected specimens were identified to Order therefore diversity was calculated by Order.

**Predator Activity**

Observational avian predator surveys were conducted on the same day and after breeding Snowy Plover surveys. Observers drove slowly on levees to scan for predators and recorded the number and species of any predators present, as well as their behavior at the time of sighting. Approximate locations were then recorded on a map. We defined avian predators as any species that have historically, or could potentially prey on a Snowy Plover nest, chicks, or adults. These include American Kestrels (*Falco sparverius*), Bald Eagles (*Haliaeetus leucocephalus*), Barn Owls (*Tyto alba),* Burrowing Owls (*Athene cunicularia*), Cooper's Hawks (*Accipiter cooperii*), Golden Eagles (*Aquila chrysaetos*), Merlins (*F. columbarius*), Northern Harriers (*Circus cyaneus*), Peregrine Falcons (*F. peregrines*), Red-Tailed Hawks (*Buteo jamaicensis*), and White-Tailed Kites (*Elanus leucurus*); gull species include California Gulls (*Larus californicus*), Herring Gulls (*Larus argentatus smithsonianus*), Ring-Billed Gulls (*Larus delawarensis*), and Western Gulls (*Larus occidentalis*); Corvid species include American Crows (*Corvus brachyrhynchos*) and Common Ravens (*C. corax*); other species include Great Blue Herons (*Ardea herodias*), Great Egrets (*A. alba*), Snowy Egrets (*Egretta thula*), and Loggerhead Shrikes (*Lanius ludovicianus*). While mammalian predators and their signs (e.g., tracks) were also recorded opportunistically, our surveys were not designed to detect mammals, since many are nocturnal.  Observed mammalian predators included grey fox (*Urocyon cinereoargenteus)* and red fox (*Vulpes vulpes*).

The average number of predators observed per survey was calculated by dividing the total number of individuals seen by the number of surveys conducted at E14.  While most predators probably have a larger territory than a single pond (Strong et al. 2004), we felt it meaningful to present indices of predator abundance at the pond scale since surveys were conducted at that level, as were inferences about Snowy Plover breeding success.

In order to document more detailed predator activity directly related to plover nest success, wildlife trail cameras (Reconyx PC900 HyperFire) were also deployed throughout the season at active nests.  Cameras were placed directly on the ground approximately three to six feet from each selected nest; this method was used after testing other further but unsuccessful placements.  Cameras were housed in a camouflage case and made even less conspicuous by using oyster shells, wood and other debris from the surrounding area.  Three rapid-fire still images were taken whenever motion was detected, in color by day and monochrome infrared by night.

We attempted to equally distribute nest cameras between all treatment types throughout the season.  Cameras were checked each time the nest was checked, typically once per week, at which time the memory card and batteries were replaced as needed.  In order to determine if predators had associated cameras with active nest locations, we deployed cameras at random locations within all three treatment types near the end of the season.  The purpose of this was to investigate whether ravens, falcons, or other intelligent nest predators were attracted to the nest cameras, and if so, to identify any differences between the treatment types.

**Analytical Methods**

We defined a nest as successful if it hatched at least one egg.  We calculated apparent nest success as the percentage of nests that successfully hatched at least one egg out of the total nests monitored.  Due to small sample sizes and analytical complications, we chose to lump all observations in all western shelled treatment plots (Old 1ha plots and New 6.47ha plot) and termed this area New 1 (Figure 3).  The 13.76ha eastern shell treatment plot is termed New 2, and all remaining untreated areas are termed Control.

*Nest Densities*

Nest densities were calculated for the entire pond and by each treatment area (New 1, New 2, Control; Figure 3).  We divided the number of nests found within each area by the available habitat within each area in hectares.  The amount of available habitat in E14 changed marginally throughout the season, relative to water management and seasonal evaporation, and was taken into account during density calculations.  In order to gauge nesting density during peak breeding windows, we calculated apparent weekly nest densities during the months of May, June, and July. Weeks during the earlier and later points of the breeding season represent minimal nesting activity and would dilute a more relevant average.

*Spatial Distribution*

Distance to nearest nest neighbor and number of nest neighbors within a 100m radius were calculated during two peak nesting weeks (April 13-19 and June 8-14). Plover nests are active for an average of 28 days therefore all nests were not active at the same time throughout the season. Plovers also nested in two major pulses in E14 this year. For these reasons we decided to use data from one week during each pulse, and more than four weeks apart, to represent nest spatial distribution within each treatment type. Spatial data was calculated and analyzed for nests in the three treatment areas (New 1, New 2, and Control; Figure 3). New Shell 1 and New Shell 2 were also treated separately to test for significant differences between the two treatment plots. The number of nest neighbors with a 100m radius was also calculated during the same two peak weeks (April 13-19 and June 8-14).

*Nest Site Selection by Treatment Type*

In order to test for significance of nest site selection by treatment type, we calculated the proportion of all nests in each treatment area (New 1, New 2, Control). We then calculated the proportion of available habitat in each treatment type. We used a chi-square analysis to compare the percent area available and percent nest use of each treatment area (Schwarz 2015).

*Nest Survival*

We used a logistic regression model to determine if nest success (hatched, not hatched) could be determined by various predictor variables including treatment type (shelled, non-shelled), nearest neighbor distance, number of nest neighbors within 100m, date of nest initiation, and date nest found. Additionally, we performed a nest survival model in program R (Rotella 2016) using encounter histories with information including date nest found, last date nest known to be present, last date nest checked, and fate date.

*Chick Survival*

Apparent fledge rates were calculated by dividing the number of banded chicks that survived to fledge (31 days post-hatching) by the total number of chicks banded. We stress that this is a rough estimate based on a sample of hatchlings, and is not an accurate measure of overall chick survival. Further and more robust analyses will be possible with an additional season of data, and larger sample size of banded chicks (see *Discussion* for more details).

*Brood Behavior*

We used a negative binomial regression analysis in program R to test if chick behavior was a product of habitat type (shelled, non-shelled) or chick age, and to test if the total number of adult foraging pecks was a product of treatment type (shelled, non-Shelled), brood age, day (throughout season), or distance to water. We used this method rather than a standard regression because our sample data were positively skewed, and did not transform properly due to a high dispersal of zero counts.

*Habitat Characteristics*
We used an analysis of variance (ANOVA) to determine if invertebrate diversity and abundance differed between treatment types over the course of the season. We used a principle component analysis (PCA) to characterize the salinity, pH, and moisture levels between treatment types over the course of the season.

## RESULTS

### Snowy Plover Surveys

Following historical trends throughout RU3, SFBBO biologists observed the most Snowy Plovers throughout the season at Eden Landing. Pond E14 supported large numbers of Snowy Plovers, averaging 80 birds per week during the 2015 breeding season. In March we observed large flocks at E14, peaking at 231 individuals, many of which were likely migrants and late wintering birds.

### Nesting Success

*Proportion Nest Fates*
In 2015, a total of 98 nests were located throughout all areas of E14 (Table 1). Of these, 59 hatched, 31 were depredated, seven were abandoned, and the fate of one nest was unknown. This equates to a nest success rate of 60%, encompassing all treatment types in this pond. A total of 50 nests were located in plot New 1 with a success rate of 70% (35 hatched, 10 depredated, 4 abandoned, and 1 unknown; Figure 5). A total of 28 nests were located in plot New 2 with a success rate of 43% (12 hatched, 13 depredated, and 3 abandoned). A total of 20 nests were located in control areas with a success rate of 60% (12 hatched, 8 depredated).

*Spatial Distribution*
Snowy Plover apparent nest density throughout all areas of E14 was 1.46 nests/ha. This is an increase from the apparent nest density during the 2014 breeding season at E14 of 0.80 nests/ha. However, since all nests are not simultaneously active and in order to gauge nesting density during peak breeding months, we calculated weekly nest densities during the months of May, June, and July. We then averaged these adjusted densities across treatment types (Figure 7).

During this peak period, the average apparent weekly nest density in E14 was 0.4 ± 0.1 nests/ha. Specified by treatment type, we found that New 1 had the highest average weekly nest density at 1.5 ± 0.5 nests/ha in New 1; New 2 had the second highest 0.5 ± 0.2 nests/ha. Control areas had the lowest average nest density at 0.1 ± 0.1 nests/ha.

The average distance to nearest nest neighbor in both New shell plots was 46.5m (min=9.4m, max=99.1m, n=52). When treated separately, nests in plot New 1 had a mean nearest neighbor distance of 41.4m (min=9.4, max=79.3, n=34). Nests in plot New 2 had a mean nearest neighbor distance of 56.3m (min=28.6, max=99.1, n=18). The average distance to nearest neighbor in Control areas was 45.6 (min=32.3m, max=76.2m, n=8).

The average number of nest neighbors with a 100m radius in both New shell plots was 4 (min=1, max=9, n=52). When treated separately, nests in plot New 1 had an average of 5 neighbors within 100m (min=1, max=9, n=34) and nests in plot New 2 had an average of 2 neighbors within 100m (min=1, max=5, n=18). Nests in Control areas had an average of 2 neighbors within 100m (min=1, max=3, n=8).

*Nest Site Selection*

Results from our chi-square analysis show that Snowy Plover nest locations across treatment types (New 1, New 2, Control) in E14 are a product of selection, and are not simply explained by chance ($\chi^2$=57.15, p=3.89e-13). Plovers selected their nest locations for shelled areas versus non-shelled areas in general, but it is unclear from our model whether nest site selection differed significantly between shelled plots New 1 and 2.

*Nest Survival*

Our linear regression model determined that nearest nest distance (p=0.213), number of nest neighbors within 100ms (p=0.068), nest initiation date (p=0.357), nest found date (p=0.771), and general treatment type (shelled, non-shelled; p=0.115) were not significant predictors of nest success (hatched, not hatched). However, we acknowledge that our model does not strongly fit our sample ($R^2$=0.26) and believe that more accurate analysis can be done with additional data from future seasons.

Additionally, our nest survival model in program R determined that constant daily survival throughout the pond was 0.97, with a 0.37 probability that a nest would survive for 33 days to hatch. Nest survival did not significantly vary between habitat types (SE=0.46; New 1, New 2, Control), and camera presence showed no impact of nest survival (SE=0.36). Nest survival rates decreased as the season progressed, and by 10% overall by the end of the season. In the beginning of the season, survival in both of the New shelled plots was slightly better than in Control areas, but survival rates decrease later in the season, and much faster in both shelled areas (New 1 SE=0.017, New 2 SE= 0.013). The age of the nest (over season) was nearly significant for survival, but not fully, as nest survival decreases when age increased (SE=0.03).

## Fledging Success

*Apparent Fledge Success*

We banded 59 chicks and 26 adults in pond E14 this season (Table 2). Twenty six of these chicks were confirmed fledged, giving an apparent fledge rate of 44% in pond E14. Chicks and adults were also banded in three other south bay salt ponds (E8, E6B, and RSF2) and when combined with E14, gave an overall fledge rate of 34% throughout the south bay. Further analyses were not meaningful with 2015 data considering our sample size and limited number of resight observations. We strongly encourage the collection of data from an additional season in order to perform more robust analyses investigating the relationship between chick success and nest treatment type, chick success and treatment areas subsequently observed in, and distance to nearest source of water.

We stress that these are apparent estimates of fledge success, and that band resighting methods are problematic in salt pond habitat due to physical and logistical limitations. We are unable to calculate a true fledge rate for this pond since we were only able to band a sample of the chicks hatched here.

*Brood Behavior*

Our negative binomial regression model showed that chick status is statistically significant for predicting the total time spend brooding (p=6.75e-12), and habitat type is not a significant predictor of behavior (p=0.222; Table 3).

## Biotic Characteristics

*Invertebrate Abundance and Diversity*

Over the course of the study, 313 individual invertebrates were collected, of which 238 were from the Diptera (true fly) family; 113 identified as *Ephydra spp.* (brine fly; Table 4). Thirty-three invertebrates were from the family Hemiptera (true bug), with 31 identified as members of the Aphididae (aphid) family. Eighteen invertebrates were from the Coleoptera (beetle) family, with 15 identified as the Western Tanarthrus Beetle, *Tanarthrus occidentalis* . The remaining 24 invertebrates were identified to the order Araneae (4), Hymenoptera (4), Lepidoptera (2), Neuroptera (1), or unknown (13).

To compare differences in invertebrate abundance between the three treatment types, we ran an Analysis of Variance (ANOVA). Our results showed that there was no significant difference in invertebrate abundance between the three treatment types (df=2, F=0.892, p=0.413; Table 5). The average length of invertebrates collected over the entire season was 2.1±1.2 mm (Table 6). Considering each treatment plot individually, New Shell averaged 2.1±1.4 mm, Old Shell averaged 2.0±1.1 mm, and Control averaged 2.1±1.1 mm.

## Abiotic Characteristics

*Salinity, pH, Temperature and Moisture*

Loadings from our Principal Component Analysis (PCA) showed no strong relationships between treatment types based on our measured variables (Figure 9). Factor one scores were just above the significance limit of 0.3 for pH (0.44), salinity (0.44), and moisture (-0.42); temperature (-.05) was below the significance limit and is not included in these results. Temperature was the only variable with a significant factor two score (0.99).

## Predator Activity

Unidentified gull was by far the most abundant predator species observed during weekly predator surveys (average of 0.85; Figure 8). Considering the time of year and geographic location, we assume that the majority of these individuals were California gulls. Peregrine Falcon (0.15) was the nest most abundant species, followed by Northern Harrier (0.12), Common Raven (0.12), Merlin (0.08), and red fox (0.04).

Thirty one of the 98 total nests in E14 were depredated giving the pond a 32% nest depredation rate. Nest camera footage confirmed that 10 nests were depredated by Common Raven and one nest was depredated by Peregrine Falcon immediately after hatching. Predator species could not be determined for the remaining 21 nests due to camera malfunctions or no camera placement on the nest.

Camera footage typically showed Common Ravens depredating Snowy Plover eggs in groups of two or three individuals. Their behavior varied between targeted nest detection and opportunistic grazing on the pond bottom. Some ravens ate eggs whole while others pecked at or tore open eggs, extracting the contents and leaving obvious signs of predation at the nest site. Without individual bands or tags, it is unclear if individual ravens had keyed in on the plover nesting colony or if nest predations were unrelated.

Nest camera footage also captured nocturnal mammalian predator activity. On one occasion, one adult fox (species unknown) was recorded walking along the pond bottom while carrying prey. One adult or juvenile fox was also recorded knocking over a nest camera and biting or clawing its exterior. Footage from randomly placed cameras showed no evidence that predatory species were attracted to cameras, or that they had associated cameras with active nest locations.

## DISCUSSION

### Snowy Plover Surveys

Following historical trends throughout RU3, SFBBO biologists observed the most Snowy Plovers throughout the season at Eden Landing. Pond E14 hosted an average of 80 birds per week during the 2015 breeding season, an increase from the average of 11, 6, 27, 17, and 46 in 2010-2014, respectively (Figure 4). It is likely that the large scale oyster shell enhancement, spread in late 2014, attracted peak numbers of breeding Snowy Plovers in this pond and further contributed to higher nest numbers and densities throughout the season. In addition to the potential positive effects on breeding success, it is beneficial for Project and land managers to recognize oyster shell enhancement as a tool for attracting breeding Snowy Plovers to selected areas.

### Nesting Success

*Proportion Nest Fates and Nest Survival*

Overall, nest numbers and nest success throughout E14 increased remarkably compared to previous seasons (Figure 6; 2012-2015), and almost doubling the number counted one season prior to enhancement. Our apparent findings are partially consistent with the original hypothesis that oyster shell enhancement will increase nest success and decrease predation rates. In general, shelled areas showed higher nest success rates than non-shelled areas. On closer examination however, we find that plot New 1 had higher nest success rates compared to Control areas, but success rates in New 2 were much lower compared to Control areas.

Nest survival models showed a 37% probability that a nest would survive to hatching throughout pond E14, and though apparent proportion of nest fates might suggest otherwise, survival did not significantly differ between treatment areas. Our strongest nest survival model showed that in the beginning of the season, survival in New shelled plots was slightly better than in Control plots, but as the season progressed (day 115-165), survival decreased much faster in them. This follows the general trend of survival decreasing throughout E14 as the season progressed. We originally hypothesized that oyster shell enhancement would improve nest survival and increase nest success, an effect that would theoretically remain consistent over the course of this season since oyster shells remained fresh and unweathered. It is currently unclear why we found results contrary to our hypothesis, though some possibilities include physiological fatigue after multiple nesting and chick rearing events, or identification of nesting areas by key predators over time.

It is important to remember that our linear regression models show no statistical significance for treatment type (shelled, non-shelled) as a predictor of nest fate. However, we acknowledge that low power values prevent us from confirming whether there is truly no relationship between treatment type and nest fate, or whether our model is simply too weak to recognize a potential relationship.

Nest camera footage also gave intriguing insight into Snowy Plover behavior and response to predation events. After each recorded nest depredation, attending adult plovers returned to their nest site alert and apparently distressed by the loss of their eggs. Adults returned to the nest site between a minimum of 10 minutes and a maximum of one and a half hours after depredation, suggesting strong variability in individual adult behavior. Returning adults removed broken egg shell fragments, cleaned nest contents, and attempted to incubate empty nest bowls for several hours after depredation. In some cases, adults intermittently returned to their empty nest bowls for another 24-48 hours.

Another intriguing incident was capture on nest camera footage in which a female was brooding chicks recently hatched chicks in the nest bowl in New 2. While she was brooding, a male appeared on camera and copulated with the female. The polyandrous behavior of Western Snowy Plovers has been well documented, as females will often abandon their broods several days after hatch and renest shortly thereafter (Warriner et al. 1986). However, it is uncommon to observe a renesting copulation at an active nest site, particularly while the female is preoccupied with brooding chicks still during the hatching process. Nest cameras not only capture valuable predator information, they also provide an opportunity to document notable variation in Snowy Plover behavior.

*Spatial Distribution and Nest Site Selection*

Enhancement plot New 1 had the highest nest density (0.4 ± 0.1), highest number of nearest neighbors, and closest neighbors (41.4m), compared to New 2 and Control areas. Plovers clearly selected nest locations for shelled areas over non-shelled areas and though it's unclear if they selected between New 1 and New 2, this general preference may explain the increased cases of nest abandonment compared to previous years. Snowy Plover nest territories are typically <0.5 ha in salt pan habitats (Warriner et al. 1986). Powell and Collier (2000) found that nest density at a dredged restoration site in southern California ranged from 0.5-3.2 and 1.3-1.7 nests per hectare over a period of 5 years. Some territories were even smaller with an average nearest neighbor distance of 36m at salt lakes in Utah (Paton 1994). Though 2015 nesting densities and nearest neighbor distances in E14 don't outstand reported values in comparable environments throughout their breeding range, Snowy Plovers have not historically nested in such high densities in the South Bay. Such a drastic change may have increased accounts of territorial aggression and documented chick mortality in treatment areas and throughout E14.

Two documented chick mortalities in E14 may have resulted from this increased aggression. On April 29, one unbanded chick was found dead on the pond bottom and in an area where a young brood was previously seen near aggressive adults. It was estimated to be three to four days old. One day prior to finding the dead chick, a male was seen in this location vocalizing and searching as if looking for a chick.

On April 27, a three-chick brood was seen roughly 350m from the original nest site where they were banded several days earlier. Two chicks were foraging and brooding normally with the male while the third chick (banded ON:RB) was immobile on the pond bottom nearby; it was not brooded as frequently as the other two. Upon inspection, ON:RB was found peeping weakly, appeared weak, but had no obvious injuries. After leaving the area to observe again, the male and two healthy chicks began moving on, leaving ON:RB immobile at the same location. ON:RB was collected to be taken to Monterey Bay Aquarium for rehabilitation. During transit, it was peeping weakly and showed unusual behavior; it was dead upon arrival and was given to biologists for testing. The diagnosis made by the pathologist was acute, multifocal severe hemorrhages on the liver, most likely due to trauma.

Potential for aggression between males and broods may increase as a result of higher nesting density, as nest territories are encroached and broods move within the entire habitat in search of optimal forage locations. These possible incidents must be taken into account when considering use of this habitat enhancement method and its effect on overall breeding success. If enhancement decreases nest predation while simultaneously increasing rates of nest abandonment, or aggression and chick mortality, the overall benefit may be negligible. Monitoring breeding Snowy Plovers for a second season in 2016 would allow us to identify if breeding activity and high nesting density was inflated during 2015, the first season after a significant enhancement event.

**Fledging Success**

*Apparent Fledge Success and Brood Behavior*

Though the apparent fledge rate in E14 was relatively promising at 44%, we stress that our sample size was small (59 chicks) and reflected less than half of hatched nests, so rates should be interpreted with caution. Further analyses were not meaningful with 2015 data considering our sample size and limited number of resight observations. We strongly encourage the collection of data from an additional season.

Current band re-sighting methods in the South Bay salt ponds involve considerable limitations, and other methods should be considered in the future to estimate fledging success. The dry salt panne habitat used by Snowy Plovers in pond E14 is uneven and highly textured, especially with the addition of oyster shells. When combined with heat waves and long scoping distances, this creates very difficult conditions for accurately resighting small color bands on adults, and even smaller chicks. In some cases, fledglings are confirmed (by SFBBO biologists or other organizations) several months after their expected fledge date and are not sighted before then. This suggests that current survey methods used in RU3 are inadequate for accurately documenting chick survival and brood activity, apart from opportunistic events. Increased monitoring effort may not be effective either since broods have the physical and behavioral ability to emigrate from E14, and into neighboring salt ponds or marshes. This further confounds our ability to consistently track known broods over the course of a season, even in a relatively small pond compared to others in the South Bay.

Use of radio telemetry to track adult males with broods, or GPS tags on individual chicks, is a promising technology for improving the accuracy of plover fledging success estimates in South

Bay salt ponds, but will also require considerable resources to implement. Regardless of the methods used, all must carefully balance the need for more intensive monitoring with the potential impacts caused by increased researcher disturbance to Snowy Plovers.

Our analysis of brood behavior showed that chick age is a statistically significant predictor of the total time spent brooding, an intuitive result considering that chicks require less thermoregulation services from adult males as they develop. Brood behavior was not impacted by treatment type suggesting that chicks were able to brood and forage with equal success regardless of enhancement. Throughout the season, biologists observed Snowy Plover chicks and adults frequently foraging in the eastern non-shelled area of E14. Broods may have been drawn here because of a wider landscape with fewer nesting territories, and increased prey availability from shallow water levels. Brood behavior may be more closely related to their proximity to water or active nests rather than treatment type, which supports our continued recommendation of raising pond water levels in order to fill borrow ditches and interior channels without flooding nesting habitat. Proximity of Snowy Plover nesting ponds to tidal mud flats, a high quality foraging habitat, will also become an increasingly important consideration as Project actions continue.

**Biotic Characteristics and Abiotic Characteristics**

*Invertebrate Abundance and Diversity*

The majority of invertebrates sampled during our study were identified as brine flies (*Ephydra spp*.) in the Diptera Order. Individuals from the Hemiptera, Aphididae, and Coleoptera Orders were the most abundant species collected, which follows typical San Francisco Estuary invertebrate species described by Larsson (2000). Feeney and Maffei (1991) found that Snowy Plover diet in San Francisco Bay salt ponds consisted mostly of flies (*Ephydra cinerea*), beetles (*Tanarthrus occidentalis, Bembidion sp*.), moths (*Perizoma custodiata*), and caterpillars. Though we found no difference between invertebrate abundance or diversity across treatment areas, plovers were observed foraging more often near water channels, borrow ditches, and shallowly flooded areas of pond bottom in the east. Considering logistical complications and inconsistent water levels, these were areas were not included in our sample design, though they may ultimately have a strong relationship with Snowy Plover success.

Our results suggest that invertebrate abundance was not affected by oyster shell enhancement, which is promising when we consider applying this method to additional salt ponds. It is beneficial for enhancement to increase nesting density, and possibly breeding success, without negatively impacting prey availability for breeding Snowy Plovers. Adjacent foraging habitat (mud flat, shallowly inundated pond bottom, borrow ditch), rather than dry pond bottom, may be more important sources of prey for breeding individuals.

*Salinity, pH, Temperature and Moisture*

Similar to our invertebrate sample findings, abiotic characteristics showed no strong relationships between treatment areas. Factor one scores for pH, salinity, and moisture were very similar but not remarkably strong and suggest that oyster shell enhancement did not negatively impact natural pond bottom conditions throughout the season. With consistent abiotic characteristics, invertebrate populations and vegetative growth can remain consistent with historical pond conditions which will prevent further risk to Snowy Plover breeding success.

**Predator Activity**

Unidentified gulls, which were likely California gulls due to season and location, were the most abundant potential predator observed at E14. The South Bay hosts an incredible California gull population, totaling 47,806 breeding individuals in 2015. Though this is a decline of over 5,000 from the 53,026 count recorded in 2014 (Washburn and Heyse 2015, Tokatlian et al. 2014), they still remain the most abundant potential predator in the South Bay and are documented predators of waterbird nests and chicks (Ackerman et al. 2013).

During a nest camera study from 2009-2011, California gulls were the species most consistently recorded depredating Snowy Plover nests in the South Bay, and the only predator documented in all three seasons (Demers and Robinson-Nilsen 2012). During this season, however, E14 nest cameras documented zero California gull activity. Of the 11 nest depredations that were documented by nest cameras, ten of them were by Common Ravens and one by Peregrine Falcons. Since nest cameras had no negative effect on nest survival, we recommend their continued or expanded use to document clear relationships between predator species, predation events, and Snowy Plover nest survival.

Consistent and problematic peregrine falcon activity was anecdotally observed throughout the season, unrelated to structured predator surveys. Peregrine Falcon populations continue to recover throughout North America (Cade et al. 1988). While most of Coastal California has not yet experienced complete recovery, urban populations have rebounded significantly (Kauffman et al. 2004), including the South Bay, where they pose an especially significant threat to nesting Snowy Plovers at Eden Landing. During 2015, a pair of Peregrine Falcons nested in a hunting blind in pond E9, approximately 200 meters from enhanced areas in E14, and fledged two juveniles by early June. Peregrine adults, and later fledglings, were consistently seen perched in and hunting over E14 throughout the breeding season. Whenever possible, biologists flushed falcons away from sensitive plover habitat though the effect was temporary. Biologists investigated prey remains and feather piles for evidence of plover predation and no Snowy Plover remains were found. Biologists observed Peregrine Falcons directly depredating Snowy Plovers on two separate occasions in 2015. In one instance, a chick was taken from the pond bottom while running with the associated male. On the other occasion, an adult male Snowy Plover was depredated by an adult Peregrine Falcon and then fed to its juvenile.

Concentrated nesting may also lead to increased predation if predators learn to cue in on nests in shell plots, as was found with Snowy Plovers at Mono Lake (Page et al. 1983). During this season, both Common Ravens and Peregrine Falcons were consistently seen hunting in pond

E14.  Both nest camera footage and in-person accounts of depredation events suggest that increased predator presence is likely to occur with increased nest density.  As Project activities continue, reducing potential Snowy Plover breeding habitat, more breeding individuals will be concentrated in smaller areas.  Intelligent predator species, like corvids, gulls and falcons, may begin to recognize these concentrated colonies and could quickly decrease plover breeding success.  It is imperative that resource and project managers continue to implement predator control efforts around E14, and throughout the Project footprint.  Habitat enhancement treatments will likely need to occur in conjunction with predator control efforts in order to best support breeding plovers.

**Restoration and Snowy Plover Nesting**

The majority of the South Bay's Snowy Plover nesting habitat is consistently located within the South Bay Salt Pond Restoration Project area.  The Project aims to restore large areas of former salt ponds to tidal marsh and managed wildlife ponds.  One of the Project's long-term goals is to support 250 breeding Snowy Plover adults within the Project area (USFWS and CDFW 2007).  While some Project restoration sites have been completed during Phase I, significant changes to potential Snowy Plover breeding habitat still remain in the Ravenswood complex during Phase II.

In 2015, 36% of Snowy Plover nests in the South Bay were found within Eden Landing ponds E12-E14.  Restoration activities have been recently completed in Eden Landing and it is now essential to continue monitoring their long term impacts on breeding Snowy Plovers.  Nearby ponds E8, E6B, E6C and E16B are also heavily used by breeding Snowy Plovers and will arguably be impacted by similar pressures including predation by Peregrine Falcon or other species, lack of nesting habitat, and access to optimal foraging habitat.  If oyster shell enhancement continues to attract breeding Snowy Plovers in E14, nest numbers and densities may continue to reach dangerous limits as breeding individuals are displaced during Phase II Project actions.

Another goal of the SBSPR Project is to increase public access in certain areas, including on levees around Eden Landing ponds E12 and E13; E14 levees are to be closed seasonally in order to minimize impacts to breeding Snowy Plovers.  At coastal breeding sites, human disturbance is a significant cause for abandonment of nest sites and lower overall nest success (Lafferty et al. 2006).  Snowy Plovers in the South Bay are very sensitive to recreational disturbance and flush from their nests when walkers are at an average 164 m when approached directly, or 145.6 m when passed tangentially (Robinson 2008 and Trulio et al. 2012).  It is for this reason that we urge Project and land managers to limit or prohibit levee access adjacent to Snowy Plover nesting colonies from March-August.  Ultimately, larger areas may need to be kept free of public access entirely in order to accommodate sensitive breeding species.

## Additional Considerations

As the amount of potential Snowy Plover nesting habitat declines in the South Bay due to Project restoration actions, nesting density must increase in order to achieve Project and species recovery goals. If oyster shell habitat enhancement proves to be a viable method, it will be necessary to pursue alternative sources of oyster shell as Drake's Bay Oyster Company, Marin County, is no longer able to provide them. Some alternatives may be oyster shell collection programs from local restaurants, or other sources from out-of-state canneries. It may be more cost effective to investigate the efficacy of alternative materials used for habitat enhancement, like gravel, heavy wood debris or other bivalve shells. These materials should be semi-permanent and able to withstand seasonal water levels and strong bay winds within the ponds. These alternatives should be tested through a pilot study before applying them on a larger scale.

Additional strategies for supporting Snowy Plover recovery are the expansion of predator management/deterrence programs, and maintaining reliable water control structures at selected ponds to ensure that dry, open panne habitat is available for nesting with nearby wet areas for foraging.

## RECOMMENDATIONS

1. Continue investigating the long term use of E14 large scale enhancement by breeding Snowy Plovers, and apply these findings to future habitat enhancement opportunities.

2. Expand banding and/or tracking methods via telemetry of chicks and adults to provide more reliable data on Snowy Plover survival rates. This is vital information needed to inform the recovery goal of 500 birds in Recovery Unit 3.

3. Continue implementing avian control programs and monitoring the effects of avian predator management on Snowy Plover breeding success.

4. Investigate potential impacts of human disturbance from recreational trail use at Eden Landing as more trails are opened to public access.

5. Investigate the impacts of Peregrine Falcon, Common Raven, and California Gulls on nesting Snowy Plovers.

6. Project and land managers should explore using alternative habitat enhancement materials or methods (oyster shell or other) as a tool for Snowy Plover recovery, and spread them in areas that will not be flooded.

7. Land managers and biologists should continue to work with contracted predator specialists and PG&E to remove predator nests from power towers, hunting blinds, and other structures around sensitive Snowy Plover breeding areas. Unused structures should be removed or treated with Nixalite to discourage predator perching.

8. Project and land managers should identify other potential Snowy Plover breeding habitat in the San Francisco Bay area, outside of the South Bay Salt Pond Restoration Project area, that can be managed for Snowy Plovers. Based on nesting information from previous years, nearly all plover nests are found within the Project area. A goal of the Project is to support 250 breeding adults; in order to reach this target in the San Francisco Bay, alternative habitat may need to be identified and managed for Snowy Plovers in addition to oyster shell habitat enhancement methods within the Project footprint.

**ACKNOWLEDGEMENTS**

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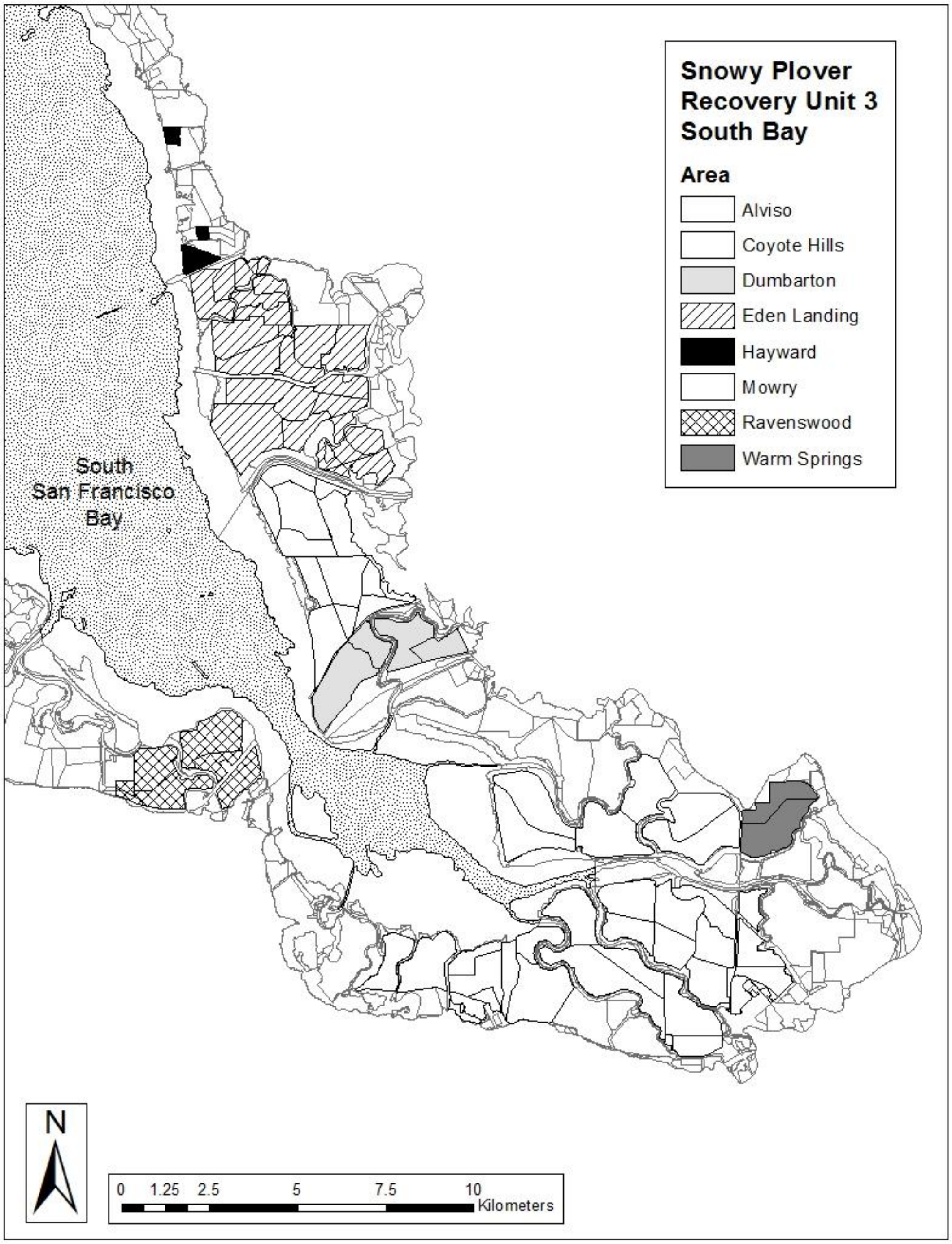


Figure 1. Areas with annually documented Snowy Plover nesting activity, South San Francisco Bay, California.

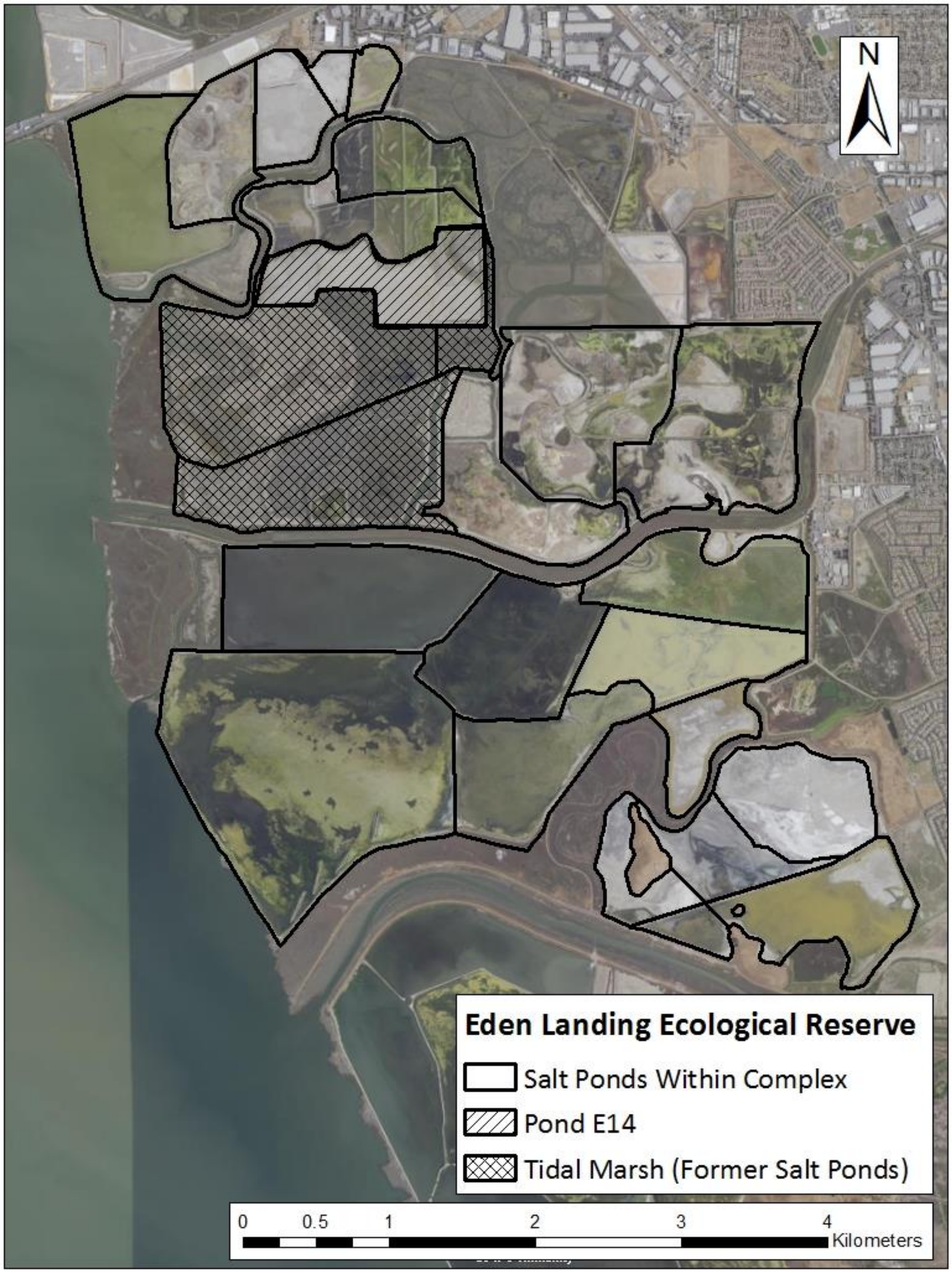


Figure 2. Salt pond boundaries and systems within Eden Landing Ecological Reserve, Hayward, California. Note that pond E14 is the location of 2015 large scale oyster shell enhancement.

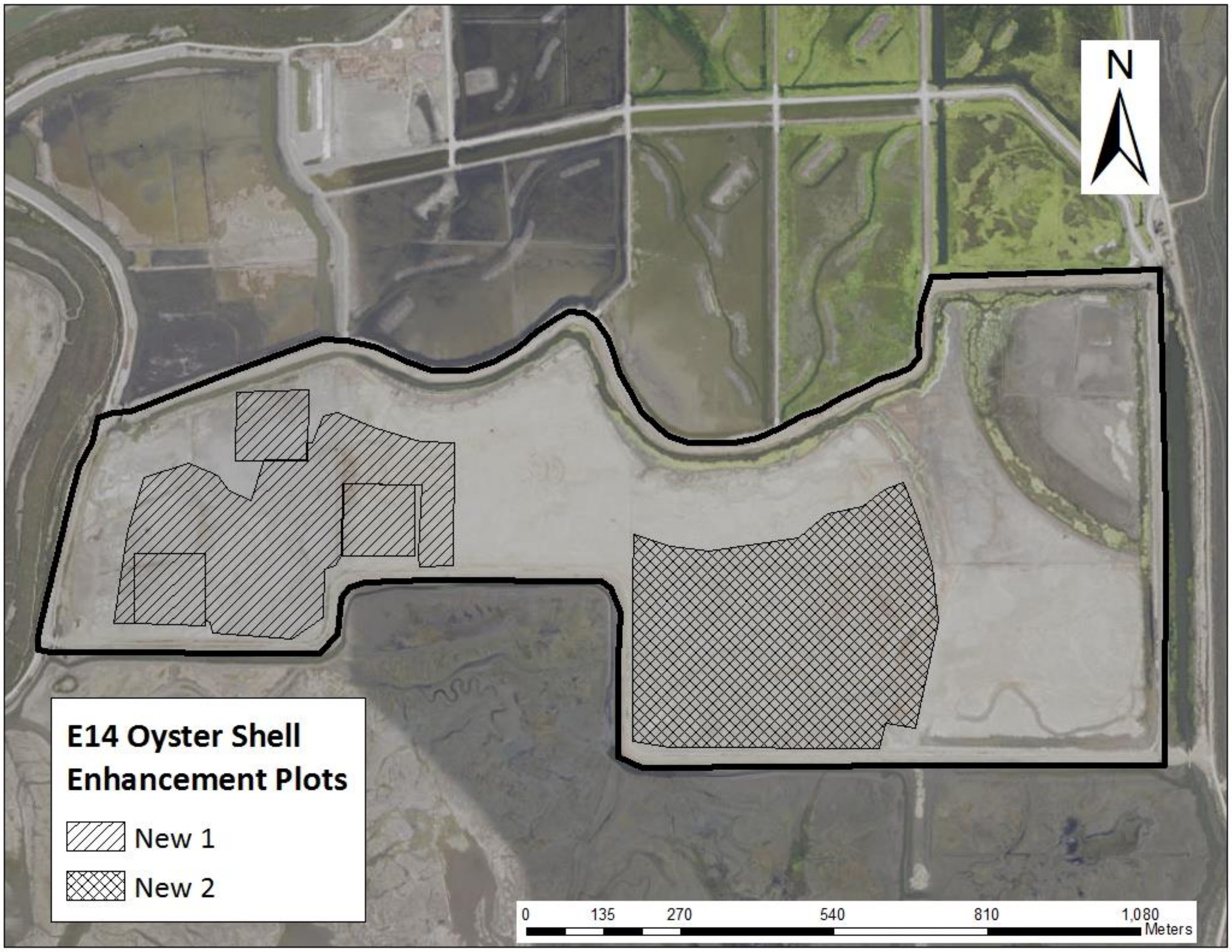


Figure 3. Large scale oyster shell enhancement plots spread in 2014 in pond E14, Eden Landing Ecological Reserve, Hayward, California. The three western squares represent the old, 1-ha pilot oyster shell plots spread in 2009; they are combined with the western large scale plot to form New 1 for the purposes of this report.

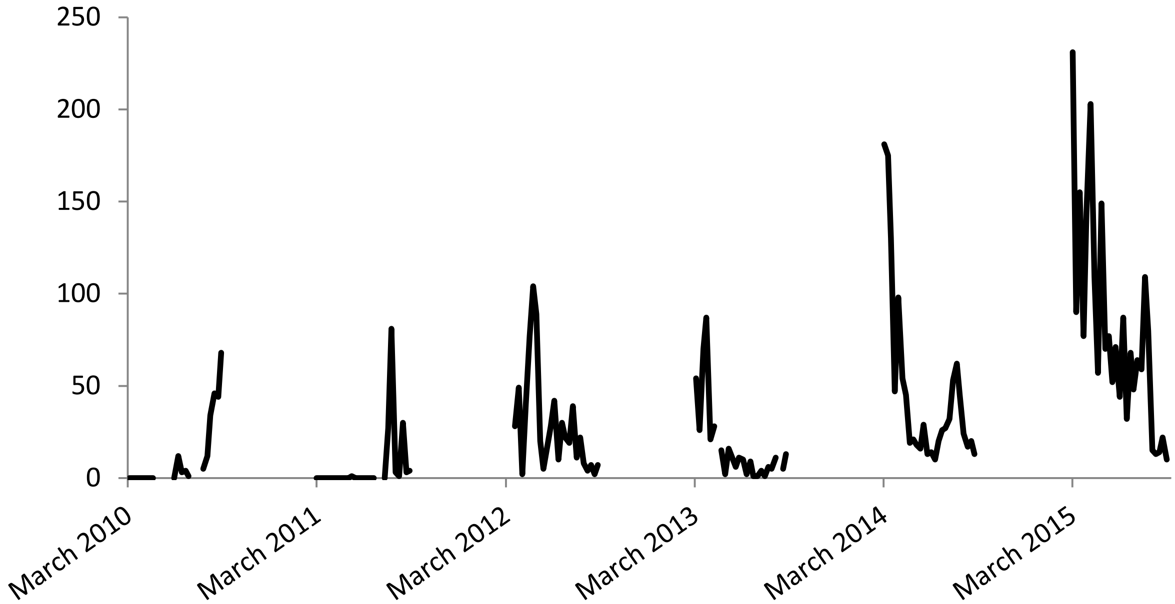


Figure 4. Weekly counts of adult Snowy Plovers in pond E14, Eden Landing Ecological Reserve, Hayward, California, 2010-2015. This figure represents adults observed on the entire pond bottom, and does not distinguish between shelled and non-shelled areas. Note: three 1-ha pilot shell plots were spread on pond E14 in 2009; large scale enhancement plots were spread in October 2014.

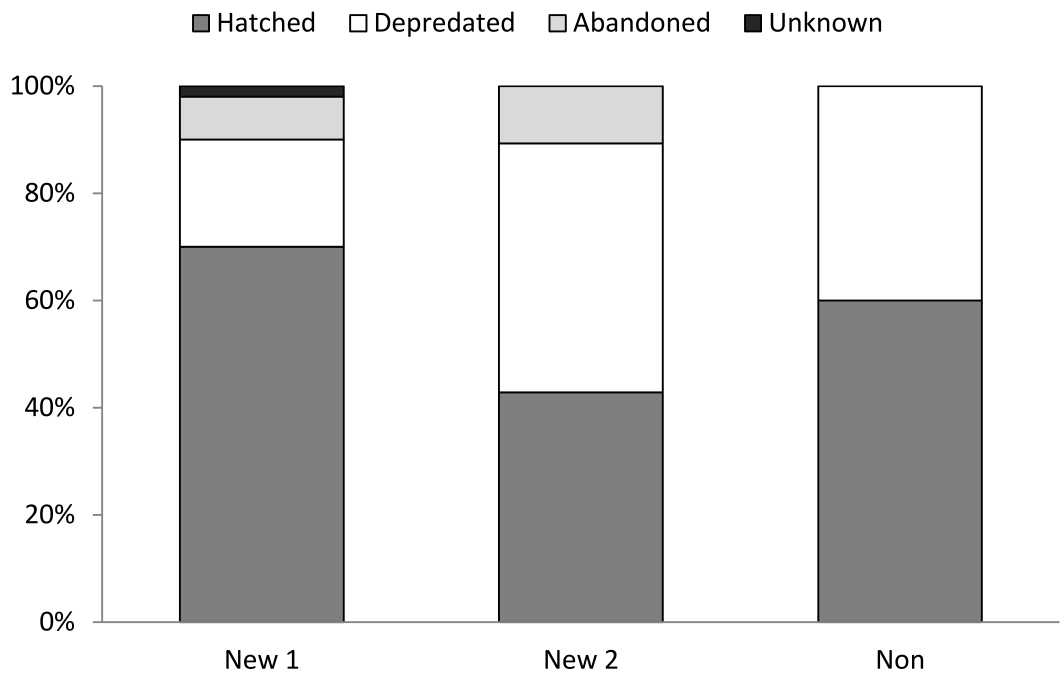


Figure 5. The proportion of Snowy Plover nest fates by treatment area in pond E14, Eden Landing Ecological Reserve, Hayward, California, 2015. New 1 represents all 1-ha pilot study plots and the large western enhancement plot; New 2 represents the large eastern enhancement; Non represents all other untreated areas of pond bottom.

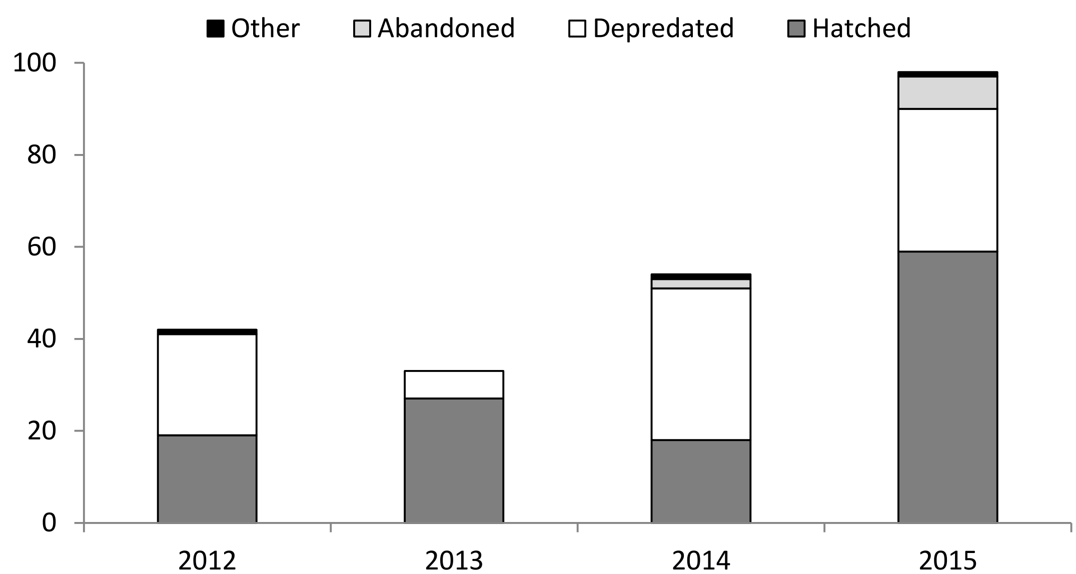


Figure 6. The proportion of Snowy Plover nest fates in pond E14, Eden Landing Ecological Reserve, Hayward, California, 2012-2015. This figure represents all nests found within the pond each season, and does not distinguish between shelled and non-shelled areas.

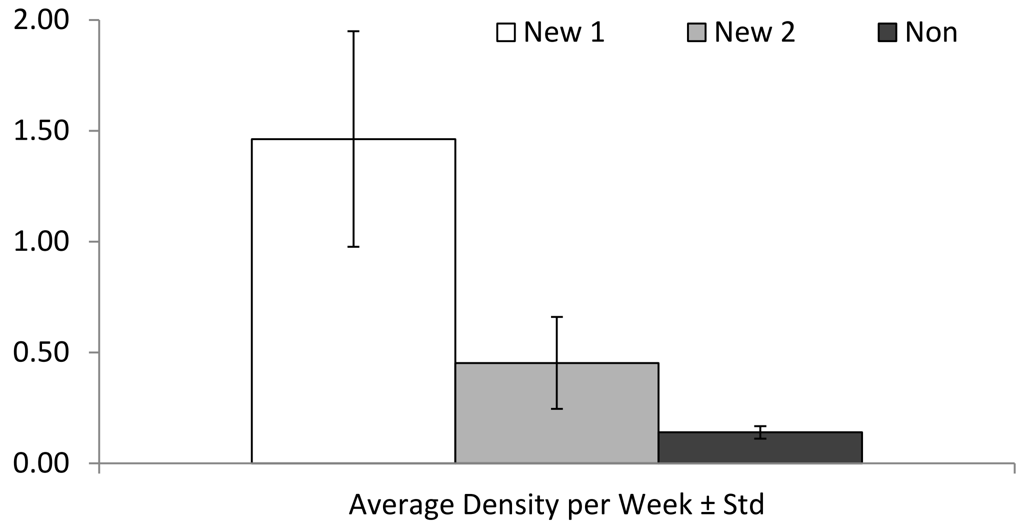


Figure 7. The average apparent Snowy Plover nest density and standard deviation in all treatment areas during peak breeding months (May – July) in pond E14, Eden Landing Ecological Reserve, Hayward, California, 2015.

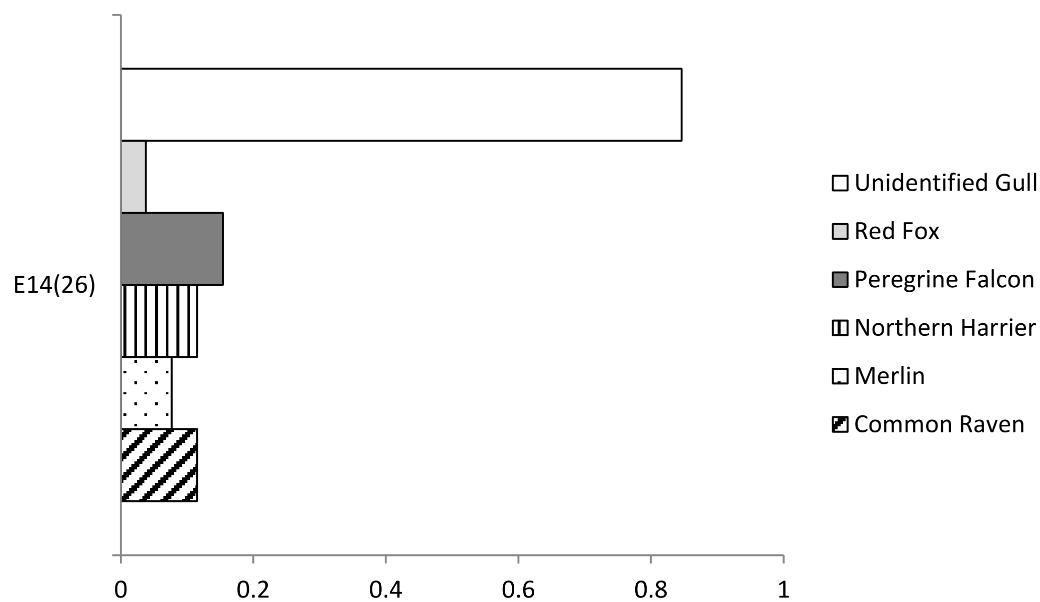


Figure 8. The average number of critical predators observed at Pond E14 during the 2015 breeding season.

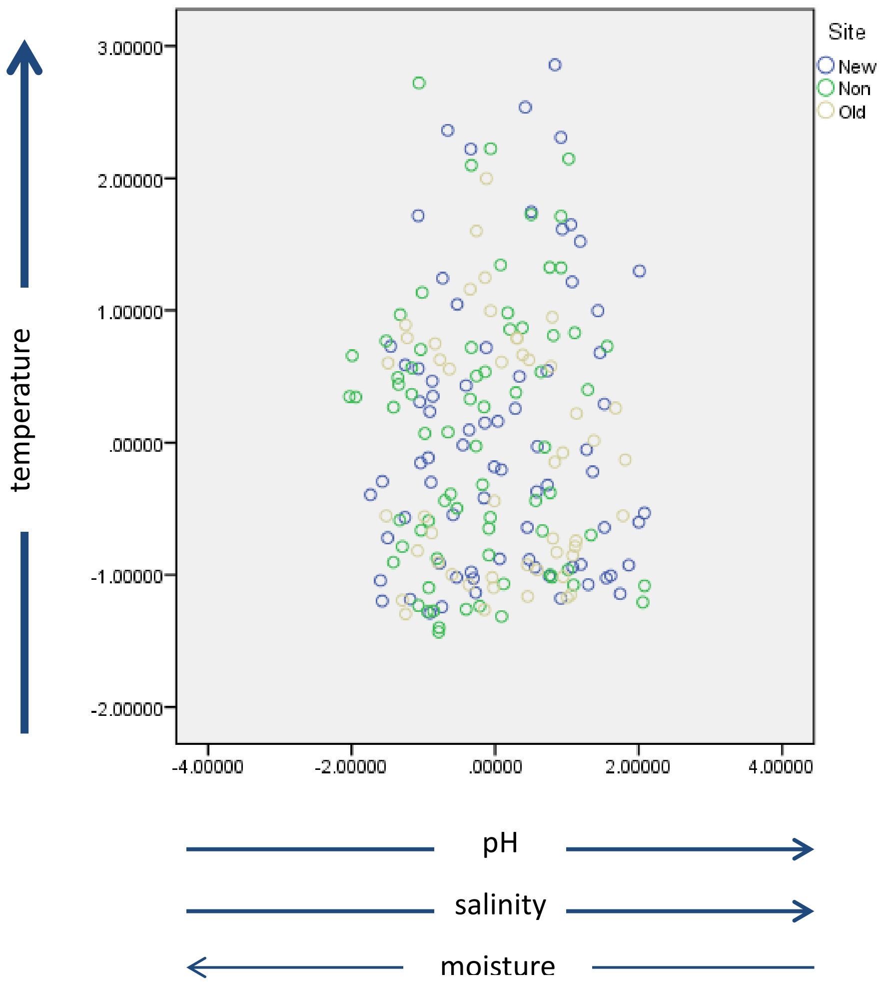


Figure 9. Loadings for principal component analysis with abiotic variables pH, salinity, moisture and temperature across treatment types (New, Non, Old).

Table 1. Snowy Plover nest fates by treatment area in pond E14, Eden Landing Ecological Reserve, Hayward, California, 2015.

| | Hatched | Depredated | Abandoned | Unknown | 2015 Total |
|---|---|---|---|---|---|
| Non Total | 12 | 8 | 0 | 0 | 20 |
| New 1 Total | 35 | 10 | 4 | 1 | 50 |
| New 2 Total | 12 | 13 | 3 | 0 | 28 |
| E14 Total | 59 | 31 | 7 | 1 | 98 |

Table 2. Apparent fledging success of Snowy Plover chicks in the South San Francisco Bay, California, 2015. Chicks were considered fledged if they survived to 31 days. N is the number of individuals banded. Chicks and adults were also banded in ponds E8, E6B, and RSF2 as part of another study and are factored into the South Bay Total apparent fledge rate.

| Pond | *N* Chicks | *N* Adults | Fledgling Success |
|---|---|---|---|
| E14 | 59 | 26 | 44% |
| South Bay Total | 116 | 38 | 34% |

Table 3. Summary of negative binomial regression values of Snowy Plover brood behavior by chick status and treatment area in pond E14, Eden Landing Ecological Reserve, Hayward, California, 2015.

| | Estimate | St. Error | z value | p |
|---|---|---|---|---|
| (Intercept) | 4.3331 | 0.547 | 7.922 | 2.34E-15 |
| ChStatus | -1.7044 | 0.2483 | -6.863 | 6.75E-12 |
| HabType | -0.3063 | 0.2507 | -1.222 | 0.222 |

Table 4. The diversity and abundance of invertebrate species sampled across all treatment areas in pond E14, Eden Landing Ecological Reserve, Hayward, California, 2015.

| Order | Family | Genus | Species | Common Name | New | Non | Old | Total |
|---|---|---|---|---|---|---|---|---|
| Araneae | Salticidae | *Phidippus* | unknown | unknown | 1 | 2 | 0 | 3 |
| Araneae | unknown | unknown | unknown | unknown | 0 | 1 | 0 | 1 |
| Coleoptera | Anthicidae | *Tanarthrus* | *occidentalis* | W. tanarthrus beetle | 5 | 8 | 3 | 16 |
| Coleoptera | Anthicidae | unknown | unknown | unknown | 0 | 0 | 2 | 2 |
| Diptera | Chironomidae | unknown | unknown | unknown | 0 | 2 | 0 | 2 |
| Diptera | Culicidae | unknown | unknown | Mosquito | 1 | 2 | 0 | 3 |
| Diptera | Ephydridae | *Ephydra* | *cinerea* | Brine fly | 1 | 0 | 0 | 1 |
| Diptera | Ephydridae | *Ephydra* | *millbrae* | Brine fly | 48 | 46 | 11 | 105 |
| Diptera | Ephydridae | *Ephydra* | *spp.* | Brine fly | 2 | 2 | 3 | 7 |
| Diptera | Ephydridae | unknown | unknown | Brine fly | 43 | 35 | 14 | 92 |
| Diptera | unknown | unknown | unknown | unknown | 14 | 9 | 5 | 28 |
| Hemiptera | Aphididae | unknown | unknown | unknown | 25 | 6 | 0 | 31 |
| Hemiptera | Cicadidae | unknown | unknown | unknown | 1 | 1 | 0 | 2 |
| Hymenoptera | Formicidae | unknown | unknown | unknown | 1 | 1 | 1 | 3 |
| Hymenoptera | Trichogrammatidae | unknown | unknown | unknown | 0 | 0 | 1 | 1 |
| Lepidoptera | Geometridae | *Perizoma* | *custodiata* | Inchworm moth | 1 | 1 | 0 | 2 |
| Neuroptera | Chrysopidae | unknown | unknown | unknown | 0 | 1 | 0 | 1 |
| Unknown | unknown | unknown | unknown | unknown | 12 | 0 | 1 | 13 |
| | | | | | 155 | 117 | 41 | 313 |

Table 5. Summary of ANOVAs between treatment areas for sampled invertebrate abundance and length. Sample size *N=95*.

| | | SS | *df* | Mean Square | *F* | Sig. |
|---|---|---|---|---|---|---|
| Invertebrate Abundance | Between Groups | 12.268 | 2 | 6.134 | .892 | 0.413 |
| | Within Groups | 632.669 | 92 | 6.877 | - | - |
| | Total | 644.937 | 94 | - | - | - |
| Invertebrate Length | Between Groups | .800 | 2 | .400 | .301 | 0.741 |
| | Within Groups | 122.125 | 92 | 1.327 | - | - |
| | Total | 122.925 | 94 | - | - | - |
| Date | Between Groups | 5.122E+10 | 2 | 2.561E+10 | .001 | 0.999 |
| | Within Groups | 1.572E+15 | 92 | 1.710E+13 | - | - |
| | Total | 1.573E+15 | 94 | - | - | - |

Table 6. The average length and standard deviation of invertebrate species sampled across all treatment areas in pond E14, Eden Landing Ecological Reserve, Hayward, California, 2015.

| Treatment Type | Average Length (mm) |
|---|---|
| All | 2.1±1.2 |
| New Shell | 2.1±1.4 |
| Old Shell | 2.0±1.1 |
| Control | 2.1±1.1 |