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Venice Beach Least Tern Colony Habitat Improvement and Restoration Study, 2006-2009

by
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EXECUTIVE SUMMARY

Here we present information on the influence of vegetation growth, dune habitat, and enclosure fencing on nest site selection and productivity of California Least Terns (Least Terns) at the Venice Beach Colony, Marina Del Rey, California (colony). This study originated from a plan to use heavy equipment to flatten dunes and remove vegetation from the colony, and contradictory observations by project biologists that terns were mostly using those dunes for nesting, and nesting successfully. This study consisted of investigating both nest site selection by the terns and the productivity of those nests under several natural and manipulated treatments. However, heavy egg predation by the American Crow at this colony exerts a strong influence on nest placement and nest success.

Our findings indicate that predation by American Crow exerts an “edge effect,” with the heaviest predation on individuals away from the center of the colony and closest to the fence. We found that nests were less likely to succeed if they were placed within 20 m of the enclosure fence, in grids with fewer than 5 other nests (<125 nests/ha), more than 5 m from their nearest neighbor and more than 70 m from the center of the colony. Additionally, terns were more likely to be predated in areas with less than 5% vegetation cover, and prefer to nest, and are most successful, in areas with 20-40% vegetation cover. We found that the best vegetation management technique was to reduce vegetation to less than 30% cover, but even this was not as successful as areas that are naturally between 5-30% vegetation cover. The terns also prefer to nest, and are most successful in areas with dunes, although our finding indicate that predation increases with the number of dunes in an area.

Based on these findings we recommend:

1. Manage the American Crow and other nest predators with a goal of decreasing the strong edge effect and colony failures. We must continue aggressive management to discourage incursions into the colony and use volunteer observers to inform staff of predation rates.

2. Nesting should be discouraged within 20 meters of the fence.

3. Control vegetation, with a goal of maintaining 20-40% cover in nesting areas within the colony. Vegetation manipulation will likely have the most impact if used to maintain open areas in the vegetated flat (Figure 2) and increase cover in the newly exposed areas (Figure 2). We should accomplish this by first removing non-native sea rocket, then selectively removing native vegetation.

4. Maintain some areas of the vegetated flat as dense vegetation as we have noted that chicks hide in this area once they leave the nest, but before fledging.

5. Maintain dune habitat where it exists and encouraging growth in the newly exposed areas (Figure 2). However, this requires further study as there may be an upper limit to the height of dunes that the terns will accept. We should use caution when clearing vegetation so that we do not destabilize dunes.

1. INTRODUCTION

This study began in 2006 in response to questions surrounding vegetation and dune management in the newly expanded Venice Beach Least Tern Colony in Marina del Rey, California (33°57'59.22"N, 118°27'30.96"W) (colony). Originally, management plans called for mechanical plant removal prior to the nesting season. This would also have flattened dunes that had formed at the site. However, we had noted California Least Tern (*Sternula antillarum browni*) (Least Tern) nesting in the dunes among vegetation and questioned this plan. In a preliminary study, we found that terns preferred to place their nests in vegetated areas and that nests placed in areas that were 1-40% vegetated had higher hatching rates and lower predation rates (Ryan 2006).

We recommended the creation of a site management plan to create optimal habitat conditions for nesting Least Terns within the enclosure. As opposed to many restoration projects that focus on re-planting damaged areas, this study would focus on the results of experimental manipulation of existing habitat to assess optimal conditions for nesting by the Least Tern. We studied the pattern of nest placement and productivity by the nesting Least Terns in response to habitat modifications made within their nesting enclosure. We will determine the most productive conditions for the terns, and make recommendations for inclusion in the site management plan.

We addressed the following questions:

- How does the presence of vegetation and dunes affect Least Tern nest selection and productivity?
- If beneficial, how should we best manage habitat to optimize nesting and productivity?

The goal of the study is to determine optimal habitat conditions for the Least Tern at this colony. We will use the answers to the above questions to inform a site management plan that will guide on-going efforts at the colony enclosure to maximize productivity of the Least Terns that nest here.

Site History. Least Terns have nested near Venice Beach since at least 1894 (WFVZ records). Until 1977, nesting in this area was poorly documented. In 1977, three pairs of Least Terns nested on the sand at Venice Beach north of the Ballona Creek mouth (Atwood et al. 1977). Beach managers placed emergency fencing around the area to protect the nests and it has remained in the same general location since. This fence has allowed the colony to continue nesting with minimal disturbance (Comrack 2001). Since 1977, Venice Beach has supported up to 16.6 percent of the statewide pairs of breeding Least Terns and over 30 percent of statewide fledglings (Ryan and Vigallon 2010). However, during the past ten years, the percentage of statewide pairs contributed by the Venice Beach Colony has declined from a maximum of 12.4 percent in 1994 to 0.4 percent in 2004. Additionally, the proportion of fledglings produced at the Venice Colony declined from 12.4 percent in 1994 to 6.9 percent in 2003, and with no productivity in 2003, 2004, and 2005 (Ryan et al. 2007a). From 1999 to 2005, this site has failed to fledge young four of seven years. American crows (*Corvus brachyrhynchos*) (crows) caused these desertions in 1999, 2002, 2004, and 2005 (L.

Comrack pers. comm., Ryan et al. 2007a). Since 2005, efforts by we and California Department of Fish and Game (CDFG) staff to protect the nesting Least Terns from disturbance and predation and boost productivity have included increasing the colony size, replacing the enclosure fence, earlier and aggressive predator control, vegetation management, and volunteer monitoring (Ryan and Vigallon 2010

Following recommendations made by biologists and the CDFG, the size of the nesting area was enlarged in March 2006 from 1.7 ha to 3.1 ha (4.2 acres to 7.7 acres) and a new fence was installed (Figure 1). The fence has thin mesh wire (chick fencing) around the bottom to prevent chicks from wandering out of the site and an angled top to keep people and other mammals from climbing into the site. Blowing sand covered the chick fence on the north side and west side. Therefore, we installed a temporary 2-foot high fabric fence approximately 10 feet inside the chain link fence to prevent chicks from escaping from the colony.

Existing Conditions.

Common plants within the enclosure include the beach primrose (*Cammisonia cheiranthifolia*), silver beachweed (*Ambrosia chamissonis*), sea rocket (*Cakile maritime*), and sand verbena (*Abronia maritima*). Beach primrose covers the dunes and flat areas on the north side of where the previous enclosure existed. In areas outside the previous enclosure, the habitat was mostly groomed flat sand. In 2007, sea rocket emerged in large numbers, filling much of the bare ground and covering the other native plant species. This may be a problem because this species is non-native, invasive and grows taller than the other native dune plants, potentially blocking the Least Tern's views of potential predators. From 2007-09 we removed as much sea rocket as possible during both the pre- and post-nesting season periods.

Preliminary Findings

In 2006, studies of nest placement and hatching rates showed that Least Terns had higher nest placement and hatching success in areas with 1–40 percent vegetation cover and a vegetation height of less than 10 cm (Ryan 2006). Studies also showed that nests placed farther from the fence had a greater chance of successful hatching and a lower chance of predation (Ryan 2006). However, the large unvegetated area adjacent to the fence made drawing conclusions about less vegetation cover difficult, as distance from the fence was an important factor in nest placement and productivity. Studies at an experimentally cleared plot suggested that this activity is beneficial for the terns.

When the fenced area was expanded in 2006, the newly enclosed areas at the perimeter of the colony were bare, flat, previously groomed sand. Areas previously enclosed since 1977 had developed native vegetation and a dune system. These freshly added areas were flat sand. Aerial photographs of the site taken after the new fence was added show the previously vegetated areas in the center and bare areas on the perimeter (Figure 1). The significance of this to our study is that we have a large number of grids on the perimeter with little or no vegetation cover, thus low vegetation height, close to the fence, far from the colony center. To confound this, previous monitors had noted that nests near the old fence had higher rates of predation. Through multiple regression analysis, we have attempted to ascertain the impact of having large areas with little vegetation and few dunes close to the fence and farther from the traditional colony center. However, even using advanced statistical techniques this is difficult to do. In summary, we suggest that despite this challenge, our analyses statistically show factors important to managing the colony for maximum potential for nesting success. Additionally, our observations provide important clues to conditions that will also help achieve these goals.

2. METHODS

Complete details of survey methods are provided in Ryan and Vigallon (2010). Details included here are those relevant to this study.

2.1 STUDY AREA PREPARATION &STUDY GRIDS

In 2006, we created a 20 x 20 m study grid based at the southeast corner of the colony using ArcView and an ortho-rectified aerial photograph of the site (Figure 1). The grid was then marked on the site using a Trimble GEO-XT GPS unit to locate the northwest corner of each grid square, which was then marked each year with a pin flag. We replaced grid markings each year in March. Prior to vegetation manipulation, we marked sensitive plant species and they were not disturbed during the vegetation clearing. We then assigned random vegetation treatments to all grids by starting at the southeast corner and assigning one of the three treatments to every-third grid. Treatments were a) no manipulation, b) reduction of vegetation to less than 30% cover, or c) removal of all vegetation (to at least 5% cover. Most grids (250 of 296, Treatments 1, 3 and 5, below) already met these criteria naturally, and no manipulations were needed. During this study, we manipulated 46 grids between 2006 and 2009.

Crews from the Los Angeles County Department of Beaches and Harbors (LACBH), local volunteers, CDFG and U.S. Fish and Wildlife Service (USFWS), conducted site maintenance in the last two weeks of March of each year. This included a) removing non-native plant species from the entire enclosure, particularly sea rocket beginning in 2007; b) then removing vegetation in pre-selected grids to specifications required by the study plan. For those grids with vegetation cover greater than the prescribed study treatment, hand crews removed vegetation until they met the treatment specifications. First, we removed all sea rocket. If not enough vegetation was cleared to meet treatment goals, then native species were removed. Heavy machinery removed sand from near the fence and crews remained within 10 m of the fence. This provided five treatment types:

1) Treatment 1: grids with less than 5% vegetation cover that were not cleared (i.e. naturally below 5%) (118 grids)

2) Treatment 2: grids cleared to less than 5% vegetation cover (28 grids)

3) Treatment 3: grids that had between 5 and 30% cover that were not cleared (i.e. naturally between 5 and 30%) (50 grids)

4) Treatment 4 grids that were cleared to between 5 and 30% vegetation cover (18 grids)

5) Treatment 5: grids that were greater than 30% vegetation cover and were not cleared. (I.e. naturally greater than 30%) (82 grids)

2.2 NEST MONITORING

We conducted site visits every 3 to 7 days from April to August to observe and monitor nesting activities. Once adult least terns arrived, we recorded observations of nest building, courtship, and anti-predator behavior. Nest monitoring involved walking through the colony, visually searching the sand surface for nests with eggs. Each nest encountered was marked using a wood tongue depressor with a letter indicating date and a number indicating order of detection on that week. We placed markers 0.5 m north of the nest. We then recorded the contents and mapped the nest using a Trimble GEO-XT GPS unit. This GPS measures at sub-meter accuracy and error was typically between 40 and 85 cm. In an effort to avoid predators associating markers with nests, we did not mark nests until 100 nests were present. We counted all chicks not in nests as well as fledglings within and adjacent to the colony. We either buried or collected dead chicks and predated eggs to prevent double counting or attracting predators.

We considered eggs "predated" that disappeared within three weeks of detection, or if they found predated eggs or other signs of predation (such as crow tracks). We considered eggs "did not hatch (DNH)," if they remained in the nest more than 28 days after discovery. We considered eggs, "presumed hatched," if they remained in the nest a minimum of three weeks, but no more than 28 days; or at nests that showed signs of hatching such as a pipped eggshell, tracks from chicks, etc. They considered eggs, "confirmed hatched," when chicks were observed at the nest or small chicks were observed within 1 m of the nest. For analysis, we combined presumed and confirmed hatched into one category, "total hatched." We included unknown-outcome nests in nest counts, eggs produced and mean clutch size calculations, but not in measures of productivity.

After completing each survey, biologists downloaded nest locations. GIS specialists then used the shape-files generated to map each nest and its alphanumeric identifier on an aerial photograph, with the grid system super-imposed. GIS specialists generated field maps each week to aid biologists in locating active nests on their next visit.

2.3 STUDIES OF NEST PLACEMENT AND PRODUCTIVITY RELATED TO LOCATION WITHIN THE COLONY.

We measured the distance from each nest to, its nearest neighbor, the colony center, nearest fence-line, and to the east fenceline (adjacent to buildings) in meters (m) using the GPS'd points and the shape map of the fence line in ArcView These were then averaged by grid each year. We then compared measures of nest placement and productivity (as described above) to their distance to the fence-line.

2.4 STUDIES OF NEST PLACEMENT AND PRODUCTIVITY RELATED TO VEGETATION AND TOPOGRAPHY

We consider the placement of nests within a grid to be a measure of habitat and location selection by adult terns made between arrival and nesting. A number of factors may influence this decision, including suitability of the nest site, competition for superior nest sites, existing nest density, and experience. Here, we use nest density described by "nests per hectare," as an indicator of preference of nest placement (Tables 1-11). Egg placement may be a function of (a) habitat, (b) location, (c) the interaction between habitat and location, and (d) behavioral considerations e.g., age and experience of pair individuals and the longevity of pair formation. However, we have limited data on the age and experience of individuals and pair history. We have used egg size and clutch size as a surrogate for these factors]

We measure productivity at these nests by number of eggs that successfully hatched and nests predated. We interpret nests that hatch to indicate that the nest was placed in a higher quality/more productive location. Alternatively, these nests may be those of older, more experienced adults. The number and percentage of chicks hatched is a measure of the ability of the parents to protect the site from predators and the parents being able to attend to the eggs successfully. Predation is the leading cause of mortality within the egg and nest failure at the colony. We interpret predation at a nest to indicate that the nest was placed in a poorer quality/less-productive location, although the age and condition of the adults are also known to be a strong influence on nest location within a colony and outcome. However, here we do not have any information on adult age or condition and this represents a limitation in our study and interpretation of the results.

We measured managed habitat variables within each grid using 20-m line transects. As part of this, for each plant that intersected the tape measure, we recorded its height, length of intersection and identified it to species. From these measurements, we calculated percent cover and average vegetation height within each grid. We estimated average dune height visually and categorized the heights as 0 m, 0.1 to 0.5 m (labeled 0.5 m), 0.6 to 1.0 m (labeled 1.0 m), 1.1 to 1.5 m (labeled 1.5 m), 1.6 to 2.0 m (labeled 2.0 m), and greater than 2 m. We used the number of dune tops to provide a measure of dune frequency.

We compared nest placement among the different categories. We obtained counts by grid and nest density (nests per hectare [ha]) by dividing the number of nests in a category by the area of grids occupied by at least one nest that matched that category at the site. We categorized productivity by nest outcome (hatched vs. predated) for all nests within each grid, and then analyzed these variables by vegetation cover, vegetation height, dune height and dune tops. We categorized vegetation cover by percentages (Table 7), vegetation height in centimeters (cm) (Table 8), dune frequency by the number of dune tops (Table 9), and dune height in meters (m) (Table 10).

2.5 DATA MANAGEMENT AND ANALYSIS.

We used measurements taken at 1411 nests between 2006 and 2009 (350 nests 2006, 532 in 2007, 458 in 2008, and 71 in 2009). We removed nests from the analysis each year for errors in recording nest contents, locations, re-locating nests, and data transfers that caused this information to be unusable. In addition, for studies of productivity, we removed all nests recorded before June 16, 2008 because 100% of the nests were predated, therefore predation was equal to nest placement and there was no difference between hatched and predated nests.

We recorded data on field data sheets, logged them in a Trimble GeoXT GPS unit, and subsequently transferred to EXCEL spreadsheets. We performed data quality assurance on 100% of the EXCEL data compared to the field data sheets.

We assessed counts, densities, and percentages for trends among the categories using EXCEL. We performed a variety of parametric and non-parametric tests for normality on the data using Analyze-it (Analyze-it 2009). Significance was defined as < 5% (<0.05). To determine whether there were significant differences among categories, we used multiple pairwise comparison tests. For cases with fewer than six categories, we used Tukey's test, when six or more categories were compared, we used Bonferroni's test.

It became apparent that several factors were contributing to differences in hatching success and predation. A forward step-wise multiple regression analysis (multiple regression) was used to investigate how each of these factors contributed to findings of significance in differences of hatching success and predation using the statistical program., Data analyses were performed using STATISTICA, (StatSoft 8.1, 2008). Data were checked for normalcy and did not require transformation. Canonical analysis was used *a priori* to identify significantly correlated variables. We used (forward) step-wise multiple regression to assess the contribution of location factors (i.e., position in the colony) and habitat (i.e., vegetation characteristics) to the probability of hatching successfully and predation. ANOVA and post-hoc tests were used to assess the variability amongst variables and the level to which factors contributed to significant findings. Significance was defined as < 5% (<0.05).

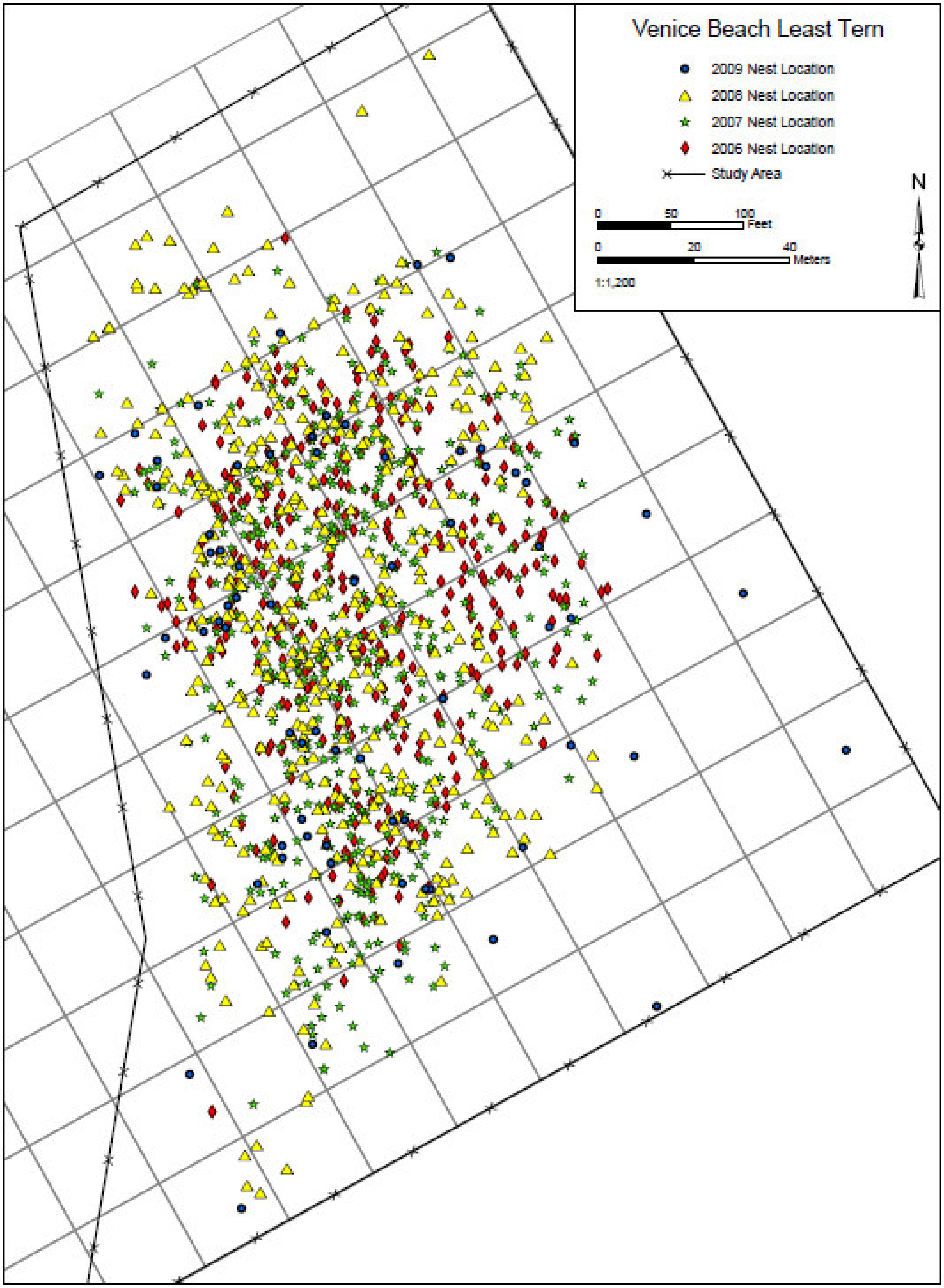

Figure 1. Map of the Venice Beach Colony Nests, 2006-09.

Figure 2. Map of the general habitat types present at the Venice Beach colony.

3. RESULTS

3.1 NEST PLACEMENT AND PRODUCTIVITY RELATED TO LOCATION WITHIN THE COLONY.

3.1.1 Nest Density

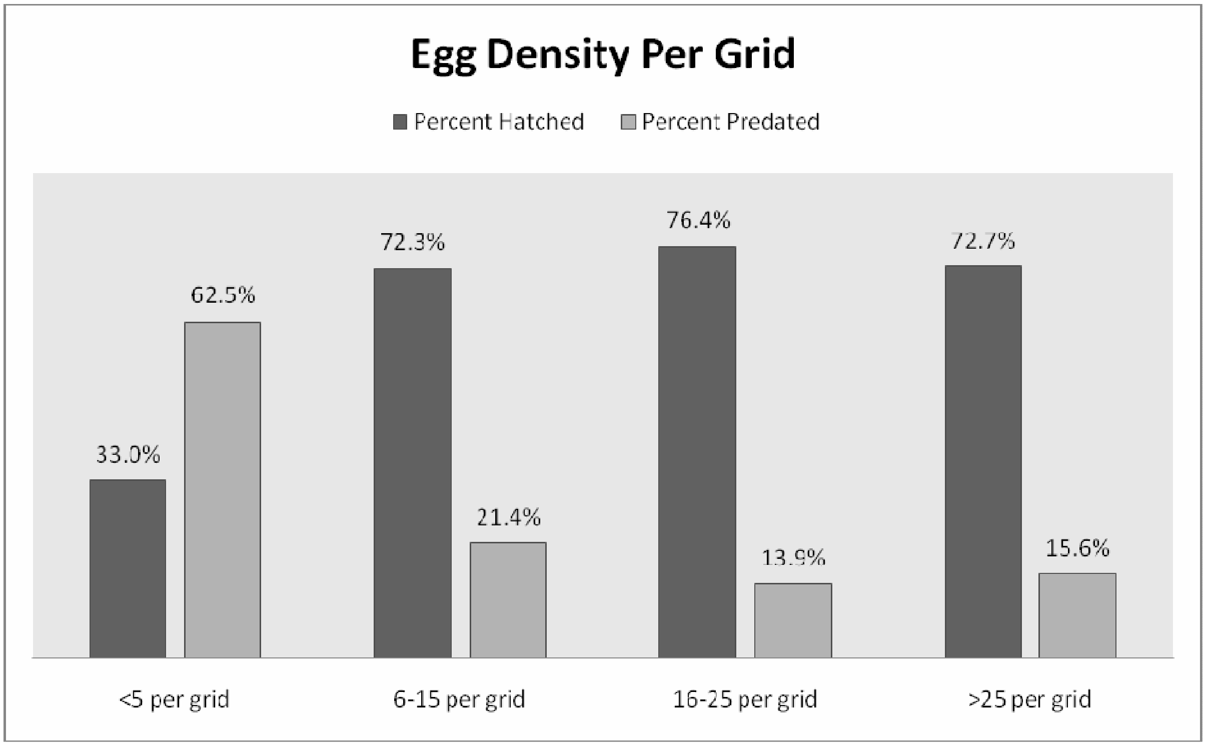

Figure 3. Density of eggs within grids in relation to hatching success and predation.

Our analyses indicate that there are significant differences among density categories of eggs per grid for both hatching success (ANOVA F = 179.5, n =104, P < 0.0001) and predation (ANOVA F = 29.8, n =129, P < 0.0001). Multiple pairwise comparisons showed that all categories of egg density were significantly different for hatching success and that all categories, except for 6 to 15 eggs per grid and 16 to 25 eggs per grid, were significantly different for predation. Multiple regression indicated that egg density was a significant contributing variable in the overall model with a positive correlation with hatching success explaining 53.1% of the variation (R^2 = 0.46, df = 6128, P < 0.0001).

The Least Terns at this colony tend to be most productive in grids with at least six nests, and were less successful in grids with five or fewer nests (Figure 3, Table 1). The highest nest density was within groups of 16 to 25 nests (Table 1).

3.1.2 Distance to Nearest Neighbor.

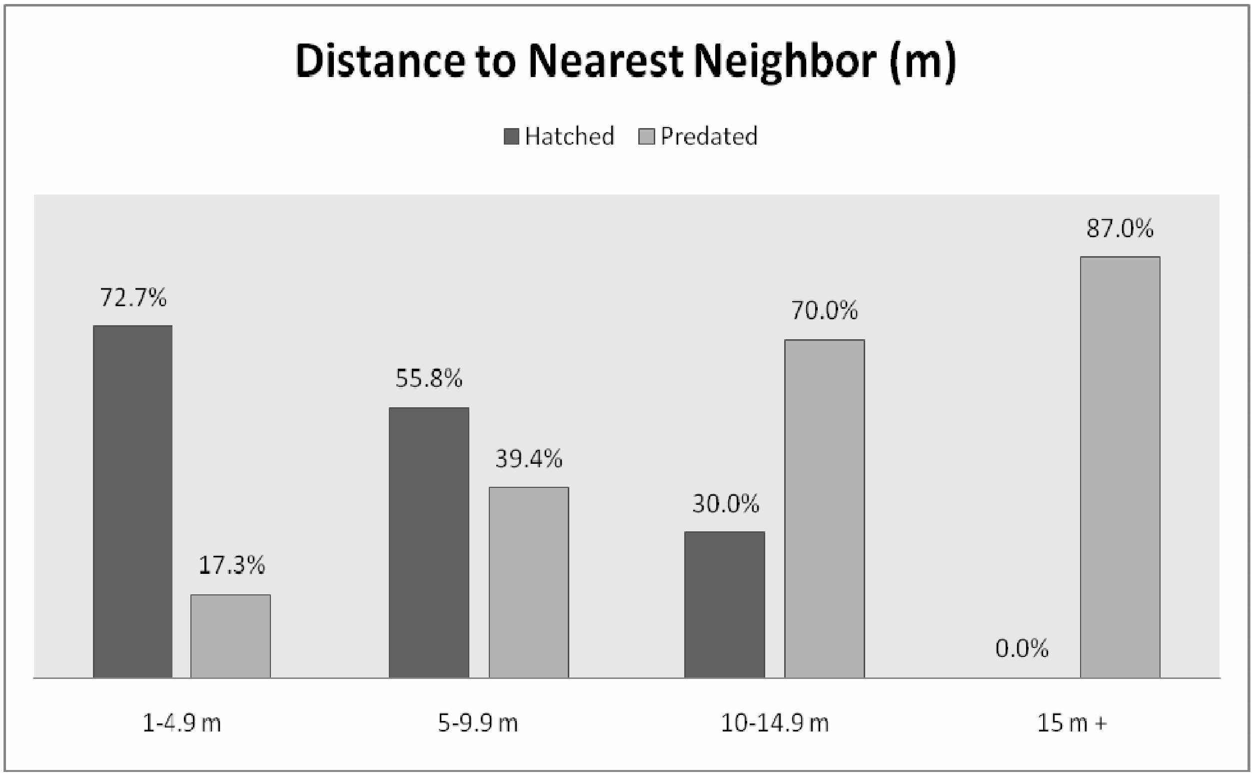

Figure 4. The relationship between the distance of nests to their nearest neighbor and productivity.

Nests placed more than 5 m from the nearest neighbor have lower productivity and higher predation rates (Figure 4, Table 2). Significant differences exist between distance to nearest nest categories for hatching success (ANOVA F = 19.2, n = 104, P < 0.0001) and predation (ANOVA, F = 12.8, n = 121, P < 0.0001). Multiple pairwise comparisons indicate that a nearest neighbor distance of 1-4.9 m have higher nest success and are significantly different from other categories, but there are no significant differences among nearest neighbor categories for both hatching success and predation. The highest nest densities occurred in areas (grids) where the average nearest neighbor was less than 5 m away. Nearest neighbor was negatively correlated with hatching success and accounted for -45% of the variation in the overall model and represented a significant portion of the variation in when analyzed with location and predation ($R^2 = 0.46$, df = 6128, P < 0.0001). Again, this indicates that terns that nest farther from other terns suffer from greater predation and lower productivity.

We also investigated distance categories within the 1-4.9 m category (Table 3). The highest nest density occurred for nests between 2-3 m apart (405.1 nests/ha). Hatching success was high among all distances (>70%) and predation was low (18% or less). Interestingly, we observed the highest rate of predation (18%) in nests 1-2 m apart indicating that with a visual predator like a crow, there may be a risk in having nests too close together. ANOVA showed these distance categories to be significantly different for both hatching success (ANOVA n = 85, F = 9.3, P < 0.0001) and predation (ANOVA n = 82, F = 4.6, P < 0.005).

3.1.3 Distance from Colony Center.

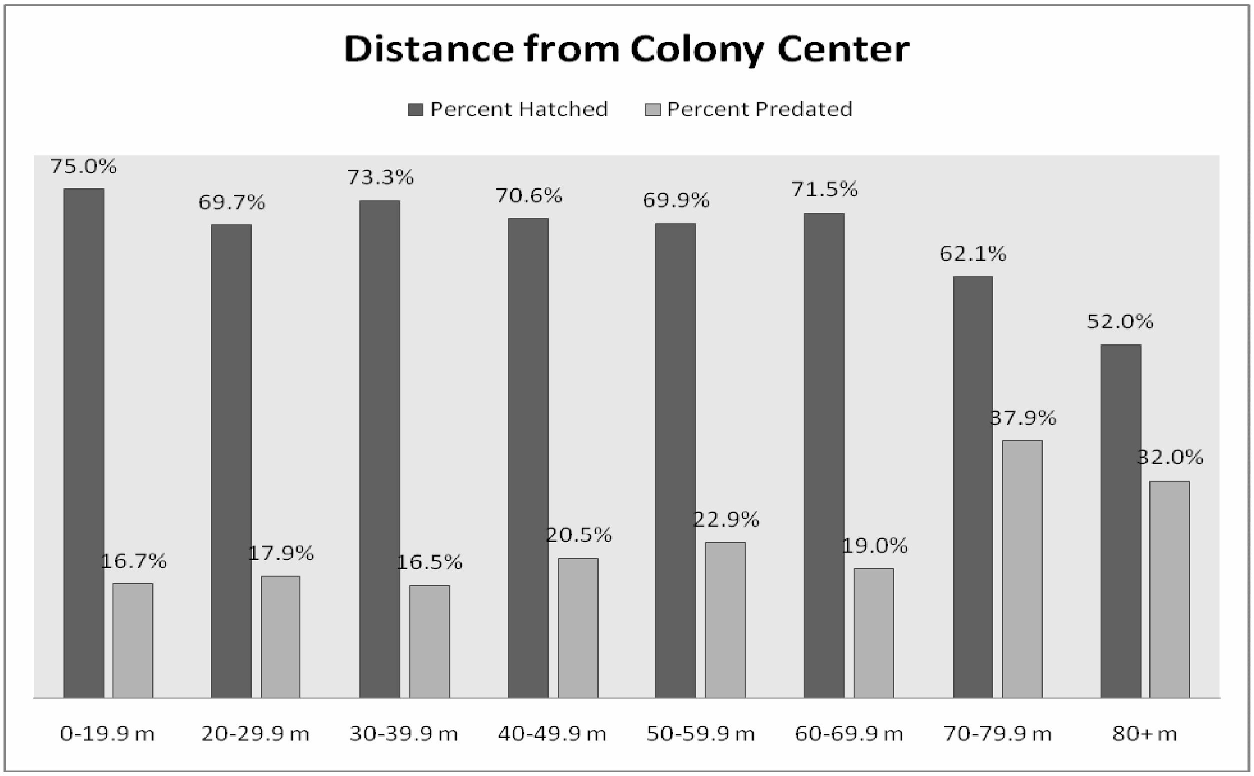

Figure 5. The relationship between the distances of nests from the colony center on productivity.

The nest distance from colony center indicated that closer is generally better. When analyzed categorically using ANOVA, we found significant differences among hatching success (ANOVA, n = 104, F = 9.6, P < 0.0001) and predation (ANOVA, n = 121, F = 7.1, P < 0.0001). We observe a decrease in productivity and an increase in predation in nests more than 71 m from the colony center (Figure 5, Table 4). Multiple comparisons show that there is a significant difference among these groups. Differences in hatching success are among groups 0-19.9 m, 20-29.9 m vs. all groups above 40 m. and 30-39.9 m and groups above 70 m (Figure 5, Table 3). The highest nest density is among grids 0-19.9 m from the center (Table 3). There was a significant negative relationship between hatching success and the distance to colony center, and represented -25% of variability in the model (Multiple regression, $R^2 = 0.204$, df = 686, P = 0.0027). We found that beyond 70 m from the colony center there was an increase in predation and a reduction in hatching success.

3.1.4 Distance from Nearest Fence.

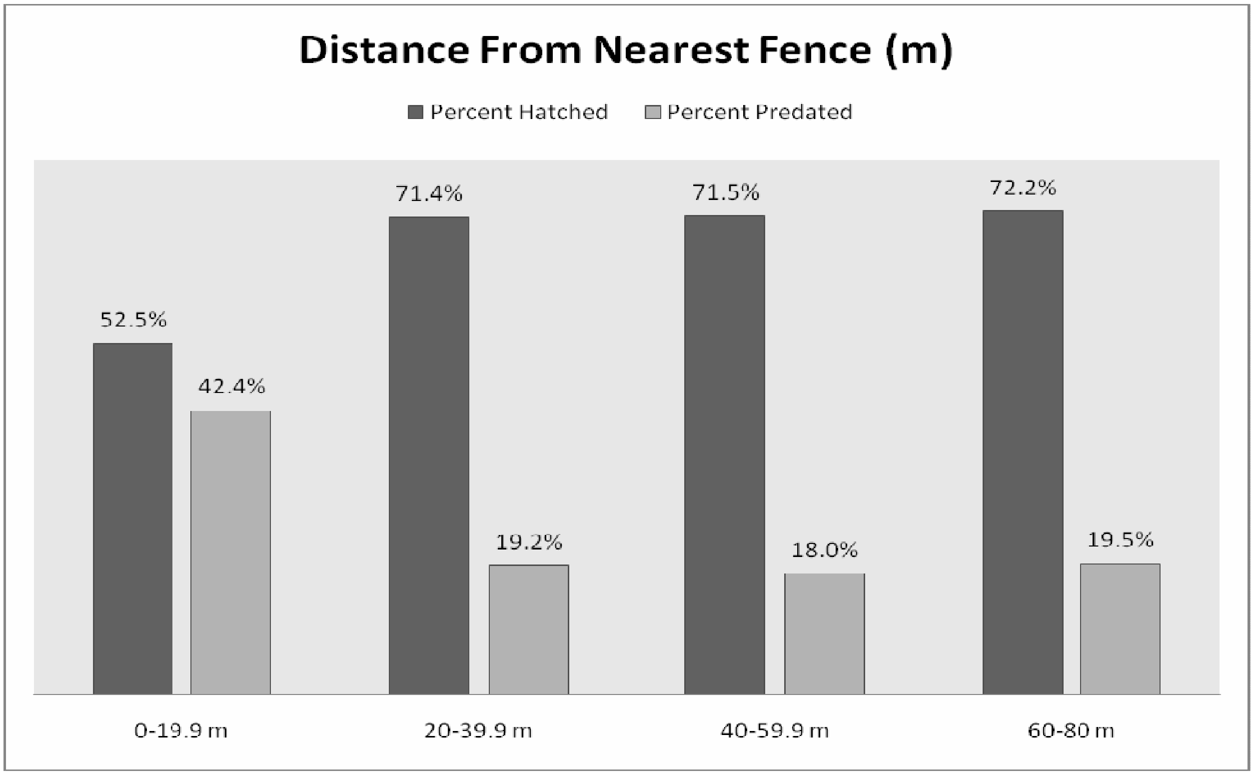

Figure 6. The relationship between distance from the nearest fence and productivity.

We previously noted that predation appears highest nearest the fence (Ryan and Taylor 2004). American crows often landed on the fence, or flew over it and landed adjacent to it, appearing to use it as cover from diving terns, and then walking into the edge of the colony. We observed that nests within 20 m of the fence have the lowest productivity and highest rates of predation (Figure 6, Table 5). The highest nest density was in grids 40-59.9 m from the nearest fence and lowest in grids 0-19.9 m from the fence (Table 5). These category groups were significantly different for both hatching success (ANOVA n = 104, F = 9.0, P < 0.0001) and predation (ANOVA n = 121, F = 5.13, P = 0.0017). Multiple comparisons show that there are significant differences among 0-19.9 m vs. 40-59.9 m and 60-79.9 m and 20-39.9 m vs. 40-59.9 m. Multiple regression analysis showed that distance to nearest fence was significant and negatively correlated with hatching success and represented -35% of variability in the model ($R^2 = 0.46$, df = 6128, $P < 0.0001$). Therefore, we find that nests placed within 20 m of a fence have a lower probability of success.

3.1.5 Distance from East Fence.

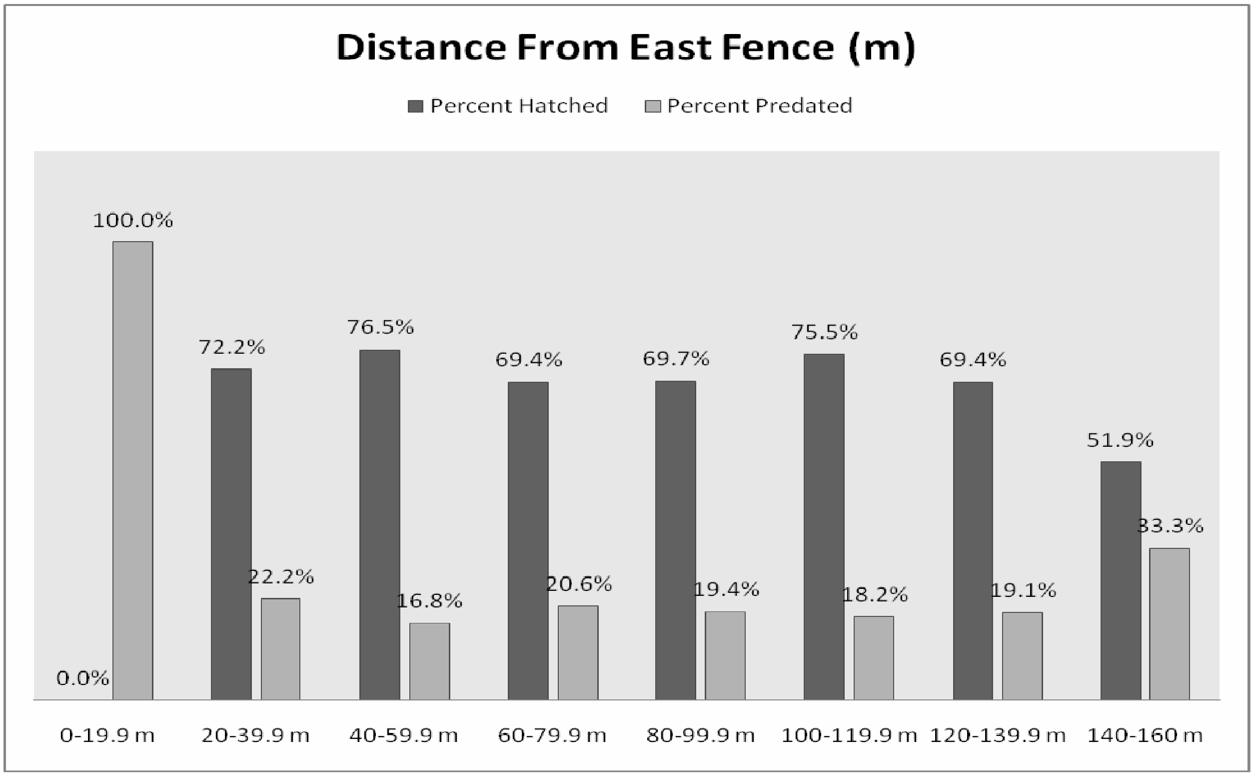

Figure 7. The relationship between the distance from the east fence and productivity.

In preliminary analysis, we observed that productivity and hatching success might be impacted even further by proximity to the east fence (Ryan et al 2007b). The east fence is closest to adjacent housing and the numerous perches that they provide for American crows. These data indicate that there is a decrease in productivity and an increase in predation within 20 m of the east fence, and that few nests are placed here (n = 2, both predated). An increase in predation and a decrease in productivity was observed between 140 and 159.9 m, which is within 20 m of the west fence (Figure 7, Table 6). We found significant differences among categories for both hatching success (ANOVA, n = 104, F = 7.2, P < 0.0001) and predation (ANOVA, n = 121, F = 2.99, P = 0.0065). However, category 0-19.9 could not be used in analysis of hatching success, as there were no successful nests. Multiple comparisons among the categories for hatching success found significant differences among 20-39.9 m vs. 80-99.9 m and 100-119.9 m as well as 80-99.9 m and 100-119.9 m vs. 120-139.9 m and 140-160 m. While the ANOVA found significant differences overall, the Bonferroni test did not detect any differences among the pairwise comparisons. Similar to the examination of distance to nearest fence, we find that there is decreased hatching success and increased predation within 20 m of both the east and west fencelines.

3.2 NEST PLACEMENT AND PRODUCTIVITY RELATED TO VEGETATION AND TOPOGRAPHY

3.2.1 Vegetation Cover.

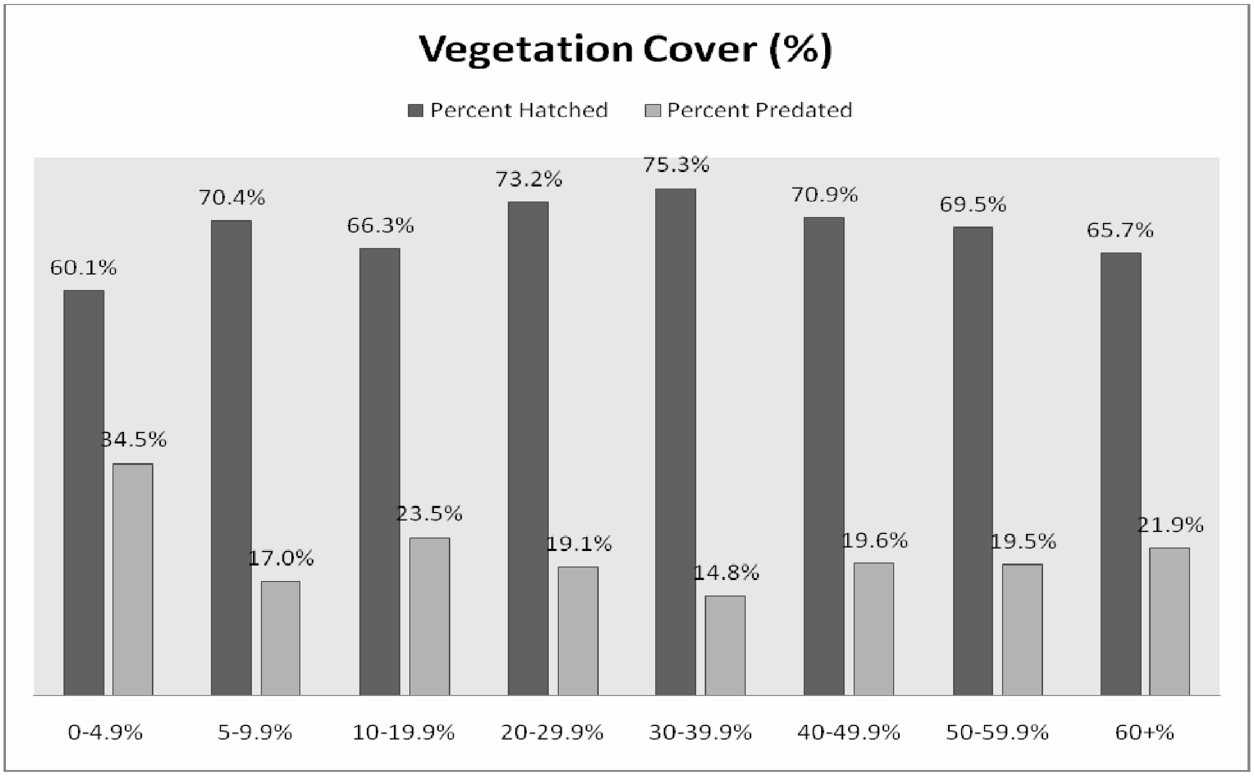

Figure 8. The relationship between vegetation cover and productivity.

Least Terns nested successfully when existing native vegetation cover was greater than 5% (Figure 8, Table 7). Vegetation cover had a significant positive relationship hatching success (ANOVA, n = 104, F = 4.7, $P < 0.0001$) and predation (ANOVA, n = 121, F = 2.82 P = 0.0093). Multiple pairwise comparisons showed that there were significant differences in hatching success among 0-4.9% vs. 5-9.9%, 20-29.9% and 40-49.9%. There were significant differences in predation among 0-4.9% vs. 20-29.9%. It appears that vegetation cover between 5% and 60% has little influence on nest success.

Less vegetated grids tended to be closer to the fence, farther from the colony center and with lower nest densities. In order to determine the relationship between the distance to nearest fence and vegetation cover, we analyzed these variables using multiple regression. We found that while there was no significant difference in hatching success (Multiple regression, R^2 = 0.0168, df = 104, p = 0.16), there were significant differences among categories for predation (Multiple regression R^2 = 0.105, df = 2118, p = 0.0015). Both vegetation cover and distance to nearest fence were positively correlated with predation, average distance to nearest fence accounted for 20.4% of variation in the model and percent vegetation cover accounted for 18.7%, both were significant.

However, in looking at nest density (nests/ha) the highest nest densities correspond with the vegetation cover with the highest success rate. Least Terns appear to place the highest densities of nests in grids with 20-39.9% vegetation cover (Figure 8, Table 7).

3.2.2 Vegetation Height.

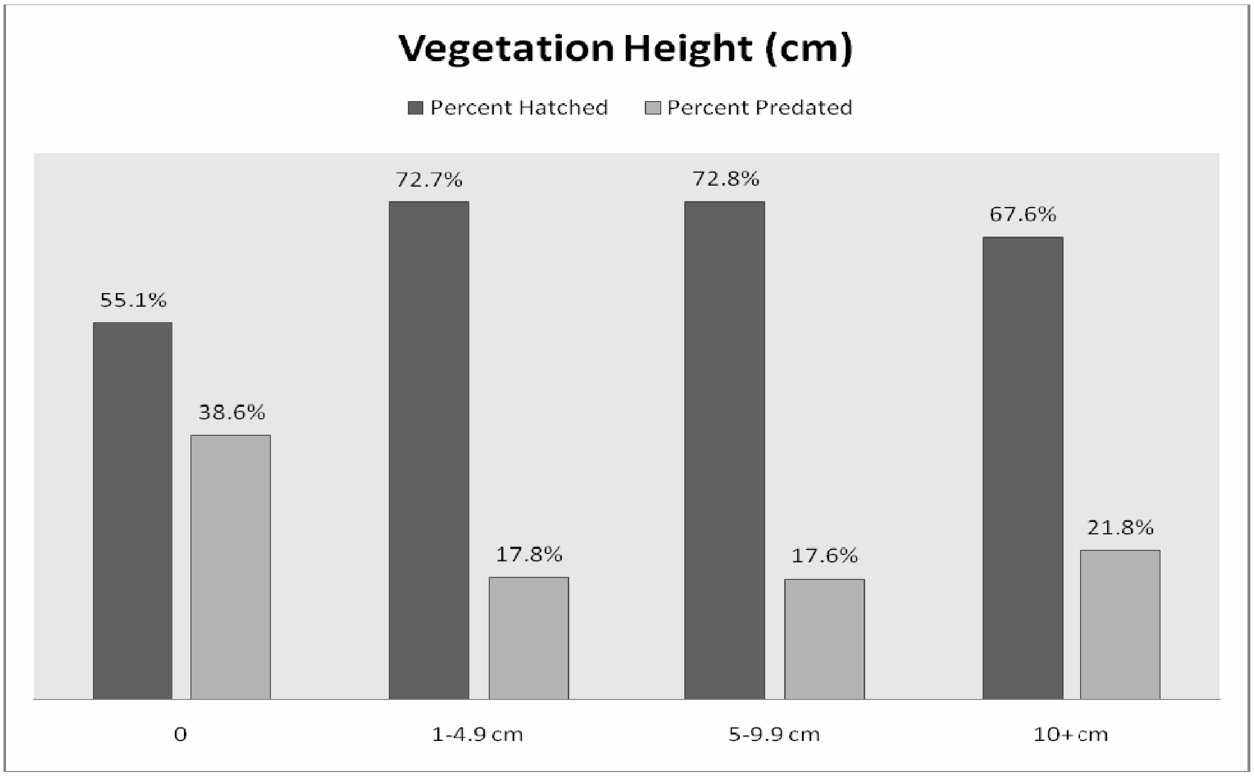

Figure 9. The relationship between vegetation height and productivity.

There was significantly lower hatching success and higher predation where there is no vegetation (Figure 9, Table 8). Again, areas with little vegetation, thus 0 vegetation height, tend to be in areas away from the colony center and near the fence. The analysis of these categories shows a significant difference in hatching success among categories (n = 104, F = 7.2, P = 0.0002), but no significant difference in predation (n = 121, F = 2.37 P = 0.0747). Multiple pairwise comparisons show significant differences in hatching success between 0 cm vs. 1-4.9 cm and 5-9.9 cm. Vegetation height was not significant factor in any of the multiple regression models we examined. Nest density among the categories is highest for grids with vegetation 1-4.9 cm and 5-9.9 cm tall. Density decreases for grids with vegetation more than 10 cm tall and the tallest average vegetation height in the colony was 16.25 cm.

3.2.3 Vegetation Manipulation.

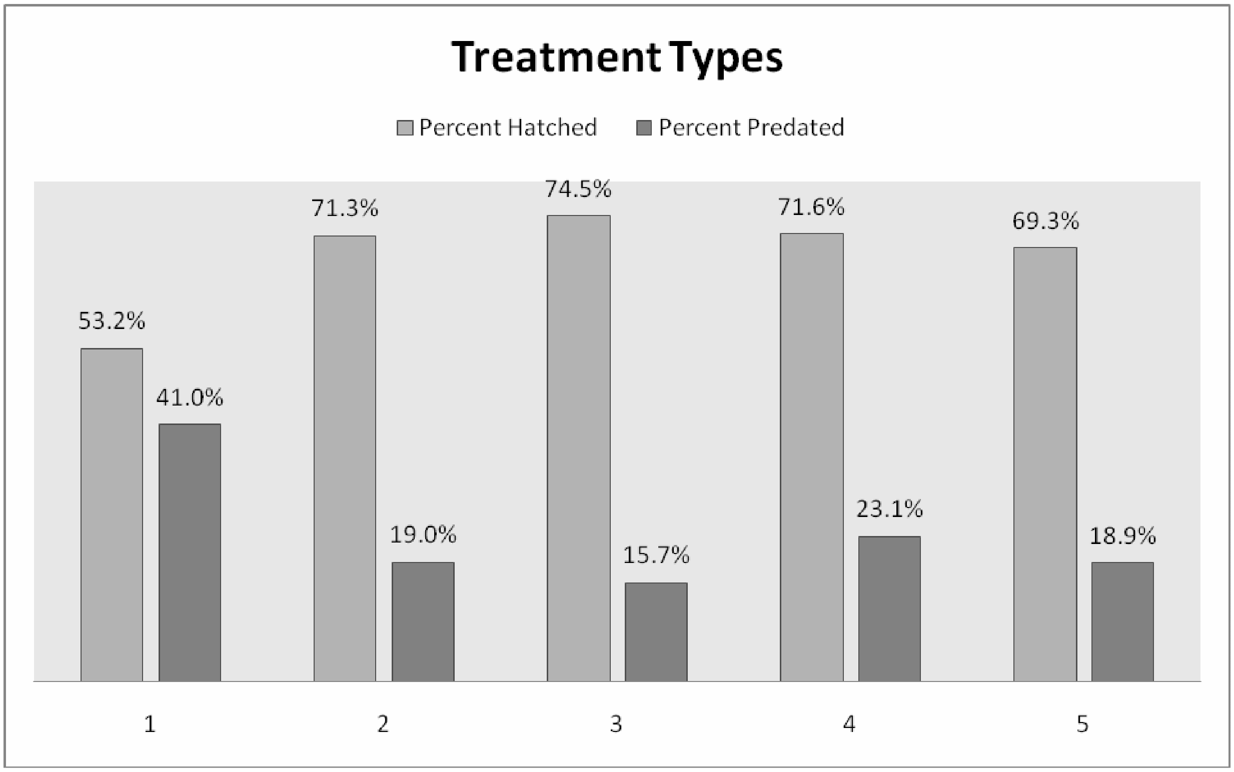

Figure 10. The relationship between vegetation manipulations and productivity.

The Least Terns were less successful in hatching nests and had more eggs predated in grids with less than 5% vegetation that were not manipulated (Figure 10, Table 9). Most of these grids were within the newly enclosed bare sandy areas, away from the colony center, and near the fences. Grids where vegetation manipulation occurred and were cleared to less than 5% and to between 5-30% (Treatments 2 and 4) were as successful and natural grids of 5-30% (Treatment 3). Grids cleared to 5-30% (Treatment 4) recorded somewhat higher nest densities than grids that were greater than 30% and not cleared (Treatment 5) (Table 9). Analysis using ANOVA indicates that there were statistically significant differences for both hatching success (n = 104, F = 9.1, $P < 0.0001$) and predation (n = 121, F = 3.3 P = 0.0138) among the five treatments. Multiple pairwise comparisons showed that significant differences among hatching success were between Treatment 1 (no vegetation, no manipulation) vs. all other treatments. Significant differences among predation were between Treatment 1 vs. Treatment 3 (5-30% cover, no manipulation) and Treatment 5 (>30% cover, no manipulation).

To investigate the interaction between treatments and distance to the nearest fence, we performed a multiple regression, using these two factors. We found that while there was no significant difference in hatching success (R^2 = 0.0062, df = 104, P = 0.50), there were significant differences among categories for predation (R^2 = 0.114, df = 2118, P = 0.0008). The average distance to nearest fence accounted for 19.3% of variation in the model and the treatment factor accounted for 21.2%, both were significant.

3.2.4 Dune Frequency.

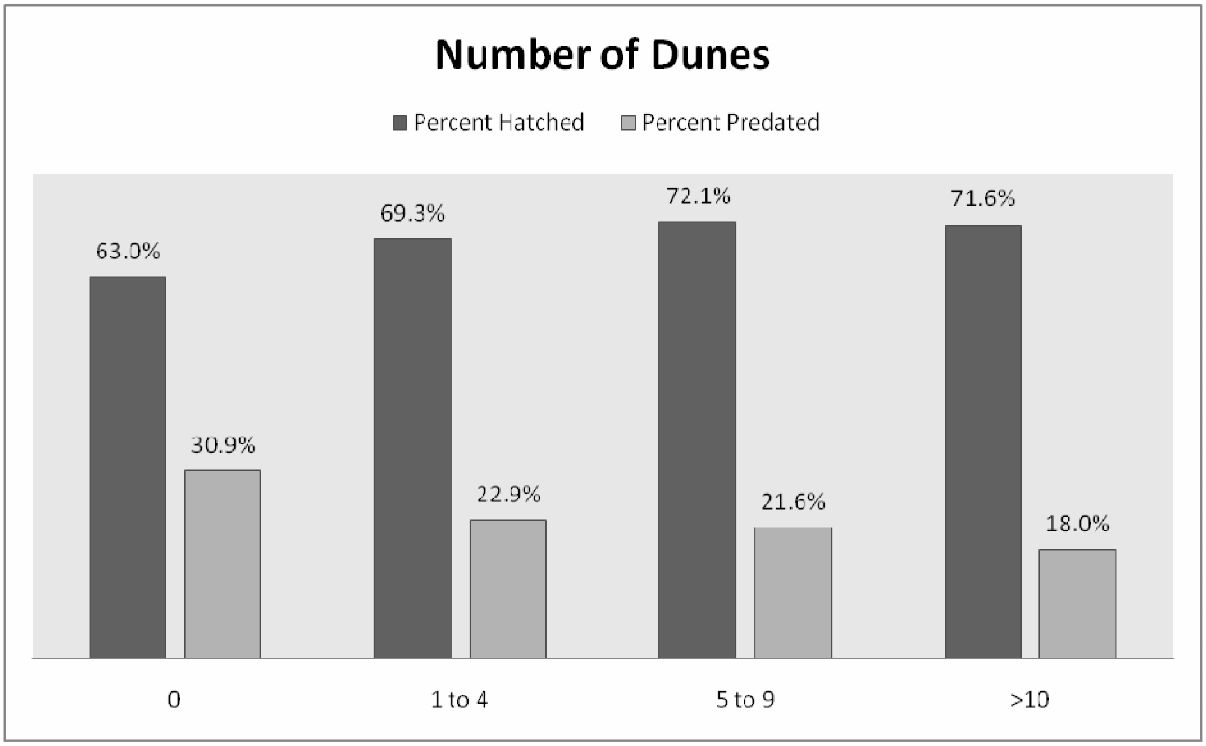

Figure 11. The relationship between the number of dunes and productivity.

We see mixed results among the analyses for the influence of the number of dunes on hatching success and predation. The multiple regression showed a negative correlation. The ANOVA detected both higher mean hatching and higher predation in dunes. Nest density was higher in areas with more dunes, and a higher percentage hatched and lower percent were predated among dunes. Figures 1 and 2 show that most nests are placed within the dunes and vegetated flat. We demonstrated that nests placed in areas with higher nest density and closer distances from the colony center have better success and less predation. The center of the colony is within the dune area. Nest placement among the categories of dune frequency was significantly different for both hatching success (ANOVA n =104, F = 19.1, P < 0.0001) and predation (ANOVA n =129, F = 9.8, P < 0.0001). Multiple pairwise comparisons showed significant differences between >10 dunes vs. 0 dunes, 1-4 dunes, and 5 to 9 dunes in both hatching success and predation. Grids with >10 dunes had higher numbers of eggs hatch and higher numbers predated, but the overall percentages of eggs hatched was as high as the other grids and the percent predated was lower than other grids (Figure 11, Table 10). We observed higher predation and lower hatching rates in areas with no dunes. We observed the highest nest density in areas with >10 dunes, the lowest in areas with 0 dunes. Multiple regression analysis found a negative correlation with hatching success and a positive correlation with predation with numbers of dunes accounting for 15.6% of the variability in the model (R^2 = 0.03 df = 5228, P = 0.22).

Taken as a whole, it appears that because 96% of nests occurred in areas with dunes, and 61% occurred in areas with more than 10 dunes, this may have made statistical comparisons difficult. Based on findings of nest placement, nest density, and percent hatching success, we conclude that dunes are a positive feature for Least Tern nesting at the colony and recommend their preservation and support measures to increase dune formation in currently flat areas.

3.2.5 Dune Height.

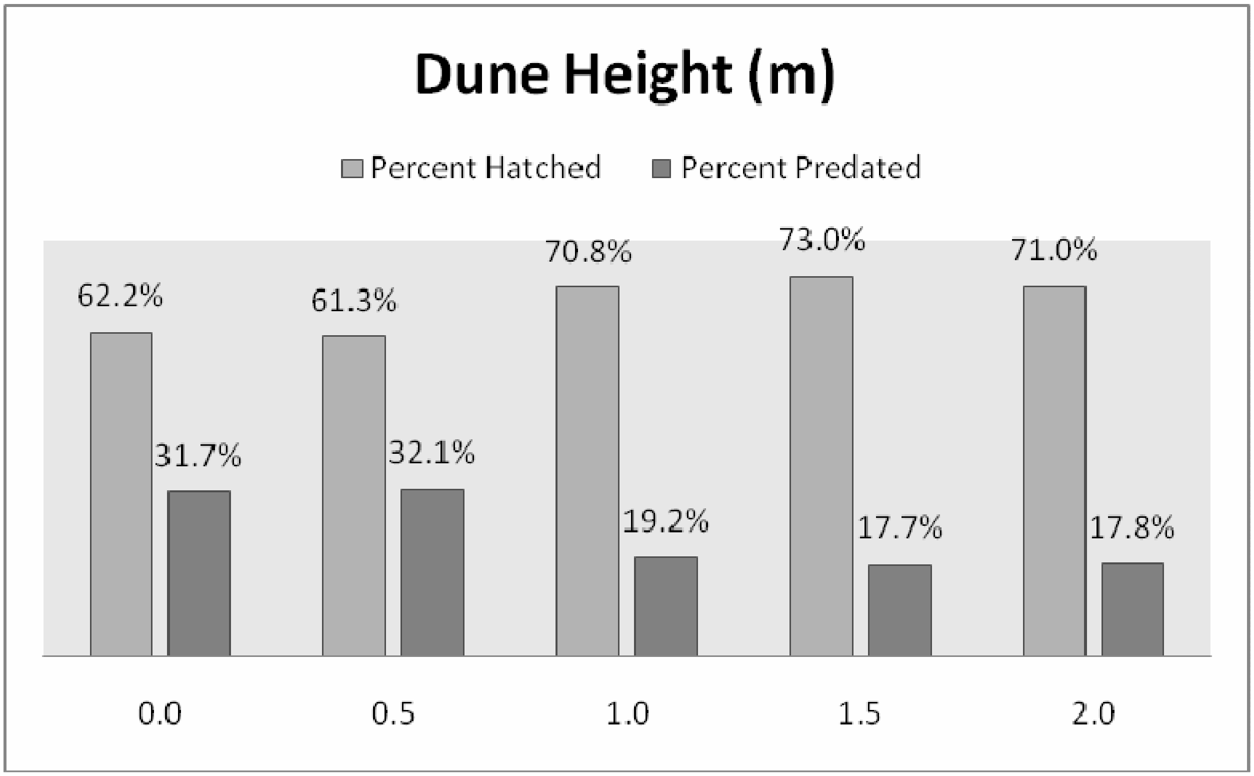

Figure 12. The relationship between dune height and productivity.

The densest nesting area is within the dune habitat (Figures 1 and 2). ANOVA showed that there were statistically significant differences for both hatching success (n = 104, F = 8.1, P < 0.0001) and predation (n = 121, F = 2.9 P = 0.0249). Multiple pairwise comparisons showed significant differences between 0 m vs. 1.5 m, and 2.0 m; as well as between 0.5 m and 1.0 m, 1.5 m and 2.0 m. Multiple regression found that vegetation height was a significant contributing variable in the overall model with a positive correlation with hatching success explaining 33.9% of the variation (R^2 = 0.204, df = 686, P = 0.0027). The highest nest density was found in grids with dune heights of 1.5 to 1.9 m (324.3 nests/ha). Overall, the higher hatching rates and lower predation were in grids with dunes between 1.0 and 2.5 m (Figure 12, Table 11).

These analyses indicate that the terns preferentially place their nests in higher densities among the dunes that have formed in the colony. They place their nests both in areas with more dunes and taller dunes. Currently these dunes remain relatively small, most are less than 2 m high. These findings suggest that terns preferentially select dune areas However; we recommend continued monitoring as the dunes increase in height to determine if there is a maximum height or density, which the terns will support. There is some anecdotal evidence to suggest that t more nests are placed on the dune tops than in the troughs, and more on the leeward side than the windward side. However, further clarification of this observation is required. Dunes may provide cover from predators and protection from the prevailing on-shore wind.

4. DISCUSSION

4.1 NEST PLACEMENT WITH THE COLONY ENCLOSURE

Analyses showed that nests placed at higher densities, closer to the center of the colony and greater than 20 m from the nearest fence had the highest hatching rates and lowest predation. Nests placed in grids with 6 or more nests and less than 5 m from their nearest neighbor were most successful. Nests placed within 70 m from the colony center were most successful. Figure 1 shows that areas that meet these criteria are mostly still within the area enclosed prior to the 2006 expansion. This area consists of natural dune habitat and vegetated flat. Areas closer to the fence, with lower densities mostly consist of newly enclosed flat, groomed sandy beach that is showing some recovery with the formation of small dune hummocks and colonization by native vegetation.

Observers noted that crows frequently predate nests near the fence and that they consume eggs perched on the fence. It provides a perch and cover for the primary predator, the American crow. Other studies of the least tern have shown that crow predation is most severe at the edge of the colony (Brunton 1997). Egg predation likely increases when food-stressed adults are away from the nest for longer periods, as has been noted in black-legged kittiwakes (Hatch and Hatch 1995). However, without the fence, the colony would be destroyed by off-leash dogs, feral cats, human intruders and other mammalian predators. Observers noted that Least Terns are successful in driving off crows when an effort is made in sufficient numbers, and with sufficient aggressiveness. It is likely that the Least Terns mobbing most aggressively are those whose nests are closest to the intruding crow and or older more experienced birds. It has been noted that seabirds that nest in the center of colonies suffer lower predation (Coulson 1968, Birkhead 1985, Wittenberger and Hunt 1985,). Alternatively, Brunton (1997) also found that this may depend on the habits of the nest predator, demonstrating that predation by black-crowned night herons (*Nycticorax nycticorax*) was more severe in the center of the colony. We suggest that a similar situation occurs at Venice, with Least Terns that nest toward the outside of the colony and in lower densities suffering higher predation. This predation increases within 20 m of the fence.

Based on these findings, we suggest discouraging nesting within grids bordering the fence by allowing them to become overgrown with native vegetation, creating a small buffer zone between the nesting colony and the fence. We also recommend measures to assist in the formation of dune formation and colonization of native vegetation in formerly groomed, newly enclosed areas. This would allow the colony to expand outward, ideally creating a greater area covered by the "colony center" effect.

However, there may be a point of diminishing returns. Our data show that if terns are too dense, it may lead to increased foraging efficiency by nest predators. Naturally, Least Terns nest semi-colonially in scattered nesting areas with low numbers of tern. By concentrating terns in small, well-defined areas, an unintended effect may be to attract more predators. Ultimately, additional tern colonies within the Los Angeles County coastline would help alleviate this threat.

4.2 VEGETATION COVER AND HEIGHT

Results indicate that the Least Terns prefer areas with vegetation; an optimal level of vegetation appears to be between 20 and 40 percent cover. Although, there may be an upper limit to vegetation cover. We have observed that several grids on the southern side of the vegetated flat are heavily vegetated and rarely used by Least Terns. From these analyses, we determine that grids with a lack of vegetation suffered higher predation and lower productivity. We recommend an optimal vegetation cover of 20-39.9%, and suggest that native vegetation be allowed to grow in areas that were enclosed in 2006 that are currently less than 5% vegetation cover. This is contrary to the 0.2–5 percent previously reported for California (Minsky 1987) and higher than reports from elsewhere in North America (5–18 percent) (Thompson et al. 1997).

The Least Terns also prefer nesting in areas where vegetation is 1 to 10 cm tall. We suggest that the presence of low-growing vegetation does not present a problem to the terns; however, there appears to be some decrease in nest density in areas with 10+ cm vegetation.

We recommend a management regime that encourages these vegetation characteristics. This could be achieved primarily by increasing vegetation in the newly enclosed areas where bare sand currently dominates. This could be accomplished through transplanting native vegetation to these areas and not conducting native vegetation removal in these areas.

At other Least Tern colonies, vegetation management is among the highest priority, however, we wish to illustrate that the Venice Beach colony has been protected since 1977 and is mostly colonized by low-growing native vegetation. Other colonies such as the Port of Los Angeles have problems with much taller weedy species such as Russian thistle (*Salsola tragus*), white sweetclover (*Melilotus albus*), Bermuda grass (*Cynodon dactylon*), and timothy grass (*Phleum pratense*). At the colony, sea rocket has been a problem in recent years and should continue to be removed regularly

These findings indicate that vegetation manipulation prior to the nesting season is a positive management technique that tends to increase nest density when vegetation becomes overgrown. However, we do not recommend the continuation of complete clearing of grids. Instead, these findings indicate that partial clearing should be done within grids that are cleared and that some vegetation should be allowed to remain to maintain between 5 and 30% cover. Grids that are naturally between 5 and 30% cover should be left alone as they are already at optimal hatching success, show the lowest predation, and the highest nest density. This is supported by findings of the highest nest density in grids with 20-39.9% vegetation cover (Sec 3.2.1, above).

We recommend the continued management of vegetation in both the vegetated flats and dune habitats. By removing vegetation from portions the vegetated flat behind the dunes to between 20-40% cover, it would likely help in increasing the nest density and expanding the colony center into these areas. Caution should be used not to reduce vegetation in all areas of the vegetated flat, as dense vegetation does provide cover for the tern chicks. Vegetation should be maintained in the dunes so that areas do not become overgrown, maintaining them below 40% cover, but caution should be used in conducting vegetation removal from dunes so it does not destabilize the dunes.

4.3 VEGETATION MANIPULATION

We find that while the optimal condition is non-manipulated vegetation at approximately 30% cover, vegetation manipulation is beneficial for nesting terns versus allowing area to become more than 60% covered or remaining completely bare. Therefore, we recommend using hand-crews to plant and transplant native plants into the newly exposed areas. We recommend maintaining the vegetation in the dune area at approximately 40% cover, first by removing non-native sea rocket, then by selective removal of vegetation so that the dunes are not destabilized. Sea rocket and other non-native plants should be cleared from the colony wherever they are found.

4.4 DUNE HABITAT.

These data indicate a preference for nesting within the dunes that formed within the previous enclosure area. These appear to be a positive habitat feature and dune formation should be encouraged. The project team recommends not conducting any sand leveling activities within the enclosure, other than those needed for fence maintenance. Further, when vegetation manipulation is conducted within dunes, care should be taken to selectively remove vegetation from the dune fronts and dune tops.

5. RECOMMENTATIONS

Based on these results and findings we recommend the following be integrated into the management of the Venice Beach Least Tern colony:

1. Manage the American Crow and other nest predators with a goal of decreasing the strong edge effect and colony failures. We must continue aggressive management to discourage incursions into the colony and use volunteer observers to inform staff of predation rates.

2. Nesting should be discouraged within 20 meters of the fence.

3. Control vegetation, with a goal of maintaining 20-40% cover in nesting areas within the colony. Vegetation manipulation will likely have the most impact if used to maintain open areas in the vegetated flat (Figure 2) and increase cover in the newly exposed areas (Figure 2). We should accomplish this by first removing non-native sea rocket, then selectively removing native vegetation.

4. Maintain some areas of the vegetated flat as dense vegetation as we have noted that chicks hide in this area once they leave the nest, but before fledging.

5. Maintain dune habitat where it exists and encouraging growth in the newly exposed areas (Figure 2). However, this requires further study as there may be an upper limit to the height of dunes that the terns will accept. We should use caution when clearing vegetation so that we do not destabilize dunes.

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Table 1. The relationship between egg density, productivity and predation.

Egg Density	Eggs	Pct Hatched	Hatched	Pct. Predated	Predated	DNH	Unkn	Count	Ha
<5 per grid	176	33.0%	58	62.5%	110	7	1	73	2.92
6-15 per grid	271	72.3%	196	21.4%	58	15	2	27	1.08
16-25 per grid	675	76.4%	516	13.9%	94	60	4	33	1.32
26+ per grid	882	72.7%	641	15.6%	138	99	5	24	0.96
Grand Total	**2004**	**70.4%**	**1411**	**20.0%**	**400**	**181**	**12**	**157**	**6.28**

Table 2. The relationship between the distance to nearest neighbor, productivity, and predation.

Near Neighbor	Nests	Nests per Ha	Eggs	Pct. Hatched	Total Hatched	Pct. Predated	Predated	DNH	Unk	Ha	Count
0-4.9 m	1297	330.9	1858	72.7%	1350	17.3%	322	175	11	3.92	7
5-9.9 m	74	66.1	104	55.8%	58	39.4%	41	5		1.12	49
10-14.9 m	9	25.0	10	30.0%	3	70.0%	7			0.36	29
15 m & <	16	26.7	16	0.0%		87.5%	14	1	1	0.6	13
Grand Total	**1396**	**232.7**	**1988**	**71.0%**	**1411**	**19.3%**	**384**	**181**	**12**	**6**	**98**

Table 3. The relationship between the distance to nearest neighbor, productivity and predation among nests less than 5 m apart.

Near Neighbor	Nests	Nests per Ha	Eggs	Pct. Hatched	Total Hatched	Pct. Predated	Predated	DNH	Unk	Ha	Count
1.0-1.9 m	156	557.1	217	71.4%	155	18.0%	39	21	2	0.28	7
2.0-2.9 m	794	405.1	1144	71.1%	813	17.9%	205	122	5	1.96	49
3.0-3.9 m	276	237.9	396	76.0%	301	15.9%	63	27	4	1.16	29
4.0-4.9 m	71	136.5	101	80.2%	81	14.9%	15	5		0.52	13

Table 4. The relationship between the distance from the center of the colony, productivity and predation.

Distance from Center (m)	Nests	Nests per Ha	Eggs	Pct. Hatched	Total Hatched	Pct. Predated	Predated	DNH	Unk	Ha	Count
0-19.9 m	189	472.5	276	75.0%	207	16.7%	46	23		0.4	10
20-29.9 m	296	435.3	429	69.7%	299	17.9%	77	52	1	0.68	17
30-39.9 m	289	328.4	412	73.3%	302	16.5%	68	37	5	0.88	22
40-49.9 m	273	220.2	385	70.6%	272	20.5%	79	32	3	1.24	31
50-59.9 m	179	194.6	249	69.9%	174	22.9%	57	16	1	0.92	23
60-69.9 m	111	115.6	158	71.5%	113	19.0%	30	14	1	0.96	24
70-79.9 m	21	75.0	29	62.1%	18	37.9%	11			0.28	7
80+ m	38	59.4	50	52.0%	26	32.0%	16	7	1	0.64	16
Grand Total	**1396**	**232.7**	**1988**	**71.0%**	**1411**	**19.3%**	**384**	**181**	**12**	**6**	**150**

Table 5. The relationship between the distance to the nearest fence, productivity and predation.

Distance from Near Fence(m)	Nests	Nests per Ha	Eggs	Pct. Hatched	Total Hatched	Pct. Predated	Predated	DNH	Unk	Ha	Count
0-19.9 m	41	51.3	59	52.5%	31	42.4%	25	2	1	0.8	20
20-39.9 m	427	194.1	598	71.4%	427	19.2%	115	51	5	2.2	55
40-59.9 m	733	315.9	1065	71.5%	761	18.0%	192	108	4	2.3	58
60-79.9 m	195	286.8	266	72.2%	192	19.5%	52	20	2	0.7	17
Grand Total	**1396**	**232.7**	**1988**	**71.0%**	**1411**	**19.3%**	**384**	**181**	**12**	**6**	**150**

Table 6. The relationship between the distance to the east fence, productivity and predation.

Distance from East Fence(m)	Nests	Nests per Ha	Eggs	Pct. Hatched	Total Hatched	Pct. Predated	Predated	DNH	Unk	Ha	Count
0-19.9 m	2	25.0	2	0.0%	0	100.0%	2			0.08	2
20-39.9 m	36	69.2	54	72.2%	39	22.2%	12	3		0.52	13
40-59.9 m	162	192.9	238	76.5%	182	16.8%	40	16		0.84	21
60-79.9 m	292	260.7	408	69.4%	283	20.6%	84	35	6	1.12	28
80-99.9 m	384	355.6	535	69.7%	373	19.4%	104	55	3	1.08	27
100-119.9 m	389	347.3	567	72.5%	411	18.2%	103	53		1.12	28
120-139.9 m	111	126.1	157	69.4%	109	19.1%	30	16	2	0.88	22
140-159.9 m	20	55.6	27	51.9%	14	33.3%	9	3	1	0.36	9
Grand Total	**1396**	**232.7**	**1988**	**71.0%**	**1411**	**19.3%**	**384**	**181**	**12**	**6**	**150**

Table 7. The relationship between vegetation cover, productivity and predation.

Percent Vegetation Cover	Nests	Nests per Ha	Eggs	Pct. Hatched	Total Hatched	Pct. Predated	Predated	DNH	Unk	Ha	Count
0-4.9%	166	90.2	223	60.1%	134	34.5%	77	10	2	1.84	46
5-9.9%	214	254.8	294	70.4%	207	17.0%	50	34	2	0.84	21
10-19.9%	136	242.9	187	66.3%	124	23.5%	44	17	3	0.56	14
20-29.9%	219	391.1	314	73.2%	230	19.1%	60	24		0.56	14
30-39.9%	373	321.6	554	75.3%	417	14.8%	82	54	1	1.16	29
40-49.9%	139	217.2	199	70.9%	141	19.6%	39	19		0.64	16
50-59.9%	88	244.4	128	69.5%	89	19.5%	25	12	2	0.36	9
60+%	76	237.5	105	65.7%	69	21.9%	23	11	2	0.32	8
Grand Total	**1411**	**224.7**	**2004**	**70.4%**	**1411**	**20.0%**	**400**	**181**	**12**	**6.28**	**157**

Table 8. The relationship between vegetation height, productivity and predation.

Vegetation Height (cm)	Nests	Nests per Ha	Eggs	Pct. Hatched	Total Hatched	Pct. Predated	Predated	DNH	Unk	Ha	Count
0	123	87.9	158	55.1%	87	38.6%	61		2	1.4	35
1-4.9 cm	211	310.3	326	72.7%	237	17.8%	58	28	3	0.68	17
5-9.9 cm	740	298.4	1046	72.8%	762	17.6%	184	96	4	2.48	62
10+ cm	232	200.0	330	67.6%	223	21.8%	72	32	3	1.16	29
Grand Total	**1306**	**228.3**	**1860**	**70.4%**	**1309**	**20.2%**	**375**	**164**	**12**	**5.72**	**143**

Table 9. The relationship between vegetation manipulations, productivity and predation.

Treatment	Nests	Nests per Ha	Eggs	Pct. Hatched	Total Hatched	Pct. Predated	Predated	DNH	Unk	Ha	Count
1	119	72.6	156	53.2%	83	41.0%	64	7	2	1.64	41
2	213	242.0	289	71.3%	206	19.0%	55	28	0	0.88	22
3	482	325.7	699	74.5%	521	15.7%	110	63	5	1.48	37
4	156	278.6	208	71.6%	149	23.1%	48	11		0.56	14
5	441	256.4	652	69.3%	452	18.9%	123	72	5	1.72	43
Total	**1411**	**224.7**	**2004**	**70.4%**	**1411**	**20.0%**	**400**	**181**	**12**	**6.28**	**157**

Table 10. The relationship between dune frequency, productivity and predation.

No. of Dunes	Nests	Nests per Ha	Eggs	Pct. Hatched	Total Hatched	Pct. Predated	Predated	DNH	Unk	Ha	Count
0	63	87.5	81	63.0%	51	30.9%	25	4	1	0.72	18
1 to 4	216	131.7	293	69.3%	203	22.9%	67	20	3	1.64	41
5 to 9	289	164.2	412	72.1%	297	21.6%	89	25	1	1.76	44
10+	843	390.3	1218	70.6%	860	18.0%	219	132	7	2.16	54
Grand Total	**1411**	**224.7**	**2004**	**70.4%**	**1411**	**20.0%**	**400**	**181**	**12**	**6.28**	**157**

Table 11. The relationship between dune height, productivity and predation.

Dune Height (m)	Nests	Nests per Ha	Eggs	Pct. Hatched	Total Hatched	Pct. Predated	Predated	DNH		Ha	Count
0.0	64	84.2	82	62.2%	51	31.7%	26	4	1	0.76	19
0.5	122	101.7	168	61.3%	103	32.1%	54	10	1	1.2	30
1.0	411	250.6	593	70.8%	420	19.2%	114	59	0	1.64	41
1.5	441	324.3	623	73.0%	455	17.7%	110	56	2	1.36	34
2.0	373	282.6	538	71.0%	382	17.8%	96	52	8	1.32	33
Grand Total	**1411**	**224.7**	**2004**	**70.4%**	**1411**	**20.0%**	**400**	**181**	**12**	**6.28**	**157**