Spatio-Temporal Analysis of Western Snowy Plover Nesting At Vandenberg Air Force Base

by

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To Judith Ann Butala, my mother

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List of Abbreviations

EHSA	Emerging Hot Spot Analysis
GIS	Geographic information system
GISci	Geographic information science
HSA	Hot Spot Analysis
MIN	Minuteman Beach Segment
NetCDF	Network Common Data Form
PCO	Purisima Colony
PNO	Purisima North Beach Segment
SAN	San Antonio Monitoring Segment
SHN	Shuman North Monitoring Segment
SHS	Shuman South Monitoring Segment
SNO	Surf North Monitoring Segment
SSO	Surf South Monitoring Segment
SSI	Spatial Sciences Institute
STC	Space-time Cube
USC	University of Southern California
USFWS	United States Fish and Wildlife Service
VAFB	Vandenberg Air Force Base
WAL	Wall Monitoring Segment

Abstract

The population decline of Western snowy plover (*Charadrius nivosus nivosus*) and subsequent listing as a threatened species by the U.S. Fish and Wildlife Service (USFWS) along the Pacific Coast, is a result of poor reproductive success that is considered directly related to habitat loss and nest predation. Habitat restoration and predator management are active key components to the recovery plan of this species. Usually "good faith" restoration plans are carried out often without the site-specific understanding of nest distribution and other factors that influence nesting to focus these efforts. Bottom-up factors, such as food availability, may contribute to the nest initiation by courting adult Western snowy plovers but these factors have not been directly assessed during the breeding season. Habitat varies between breeding sites; therefore, it is important to determine spatial patterns and regionally unique nest site selection for management actions. The goal of this study is to better inform management regarding where future habitat restoration or predator management activities need to be focused at Vandenberg Air Force Base.

This thesis looked at the spatial and temporal changes in Western snowy plover nesting from 2002-2018 using Hot Spot Analysis to determine clustering of nest predation, initiation, and success throughout the breeding site. Specific areas of habitat were identified as significant hot spots in each nest category. These areas did not vary significantly year to year, however, analyzing 17 years together summarized hot spot trends overall which pinpoint significant areas where management actions should focus. Additionally, an exploratory analysis using habitat data on wrack abundance was used to identify possible spatial correlation between this habitat variable and nesting. The result of this analysis suggests no correlation between high wrack abundance and nesting, rather it indicates that low wrack abundance was more prevalent than high abundance during nest initiation.

Chapter 1 Introduction

Conservation management of threatened and endangered species populations under the Endangered Species Act is constantly balancing the protection of wildlife with the allocation of funding available that benefits the most species and habitats. Many resources are used to fund and implement large management plans designed to aid in recovery of these species. Finding "hot spots" or statistically significant clusters of biological data such as endangered species locations is needed so that priority areas for management and restoration projects can be distributed appropriately to support recovery goals (Trindade-Filho and Loyola 2011; Meyers et al 1999). Therefore, research that examines nesting patterns, including their distribution and related conditions in the environment that influence a species survival or reproductive success, are crucial in allocating resources appropriately.

In the last several decades, habitat and predator management have been at the forefront of the threatened Western snowy plover recovery plans in the coastal areas of California (USFWS 2007). Invasive plant species such as European beach grass (*Ammophila spp.*) have taken over the coastal dunes throughout the plover's breeding range altering habitat structure, reducing available nesting areas, and impacting nest success (Muir and Colwell 2010; Zarnetske et al. 2010). Common predator populations such as coyote and raven have risen steeply in coastal areas and have been directly linked to reduced Western snowy plover reproductive success (Page et al. 1983; Neuman et al. 2004; Burrell and Colwell 2012).

Removing nest predator and invasive plant species (habitat restoration) are common practices in most Western snowy plover management plans to increase reproductive success. Many "good faith" restoration activities continue in breeding areas on the idea that if you restore it, the species will use it (Ahlering and Faaborg 2006). However, some habitat remains unoccupied by breeding plovers despite these measures (Robinette et al. 2017). Other factors may be at work to influence where plovers place nests, including nesting densities or conspecific attraction (Nelson 2007; Leja 2015; Patrick and Colwell 2017) and bottom-up environmental changes such as algal wrack deposits that serve as food resources for nesting birds (Dugan 2003; Lafferty 2013; Robinette et al. 2017).

This thesis analyzed and summarized the annual Western snowy plover nest initiation, predation and hatching hot spots throughout Vandenberg Air Force Base breeding area. In addition, the relationship between the spatial patterns of annual plover nesting to algal wrack deposits or food resources was explored. The research goal was to better inform plover managers of where and when to focus restoration and predator management efforts.

1.1 Western Snowy Plover Breeding Ecology

Western snowy plover (herein referred to as plover) is a threatened shorebird listed by the USFWS under the Endangered Species Act on March of 1993. The population decline leading to the plovers' listing is a result of poor reproductive success due to habitat degradation, human disturbance and predation of eggs and chicks (Page and Stenzel 1981; Page et al. 1991; USFWS 2007). The population's range extends from southern Washington to Baja California, Mexico, with the majority breeding from southern San Francisco Bay to southern Baja California (Page and Stenzel 1981; Palacios et al.1994).

Figure 1. Adult Western Snowy Plover

The plover primarily nests in sparsely-vegetated dunes, sand spits, dune backed beaches, river mouths, lagoons, and salt pans (Page and Stenzel 1981). Nesting begins in early March with hatching continuing through mid-August. Pairs of birds often nest multiple times during the breeding season with an ability to re-nest within two weeks after a failed nesting attempt (Warriner et al. 1986; Page et al. 1991). After a failed nesting attempt, plovers may move hundreds of kilometers to nest at another site or re-nest at the same location (Stenzel et al. 1994; Powell et al. 1997). Clutches usually consist of three eggs and are incubated an average of 27 days by both sexes (Warriner et al. 1986). Once hatched, plover chicks leave the nest cup within hours of hatching to look for food and are cared for by the male for an average of 28 days until fledging. During this time, chicks crouch and hide from predators amongst the wrack and other debris on the beach front between feeding on invertebrates and being brooded by the male.

Plovers rely on terrestrial invertebrates, foraging primarily in the intertidal zone, on the wet sand, and within algal kelp deposits (Dugan et al. 2003; Schlacher et al. 2017). Plovers use visual cues to capture prey on the surface and in the air by running and pecking at kelp flies (Page et al. 1995).

1.2 Study Area

Vandenberg Air Force Base (VAFB), provides 13.8 miles of protected coastline for the largest snowy plover breeding populations in California by closing beaches to the public during nesting season from 1 March until 30 September and conducting extensive management. However, limited recreational access is open throughout approximately 1.25 miles of breeding habitat during the plover breeding season.

Management includes predator control, beach closures, focused research, invasive plant removal, dune recontouring and nest monitoring. VAFB has conducted intensive monitoring of the population since 2001 and more recently began an ongoing beach restoration project which aims to provide additional suitable nesting habitat (Robinette et al. 2017). Due to the management at VAFB, the relatively remote location of the breeding sites, and the fact that most of the beaches are relatively undisturbed by human recreation activities; VAFB is an ideal site to analyze nesting distribution, suitability, and factors impacting to nesting.

VAFB plover breeding occurs on three geographically isolated beach sectors referred to as North, Purisima, and South beaches (Figure 2). These three sectors are further divided into nine monitoring segments shown in Figure 3. North beaches stretch 6.2 miles from Minuteman beach to Purisima Point and are characterized by wide sandy beach fronts with significant back dune that extends in some areas one mile inland. This sector is further separated into four monitoring segments: Minuteman (MIN), Shuman North (SHN), Shuman South (SHS), and San Antonio (SAN). MIN is comprised of 1.1 miles of sandy beach with heavily vegetated dunes and includes 0.25 mile “open area” which is open during breeding season to military personnel recreation. SHN segment begins at Shuman Creek south 1.6 miles to No Name Creek. Habitat in this segment is comprised of moderately vegetated back dune with extensive open sand sheets.

SHS extends 1.4 miles from No Name Creek south to San Antonio Creek. It is characterized by narrow beach fronts with sand sheets surround by dense vegetation cover. SAN begins at San Antonio Creek south 2.1 miles to north rocky Purisima Point. Habitat is comprised of wide sandy beach fronts with extensive open sand sheets with sparse vegetation.

Purisima beaches incorporate bluff back pocket beaches and dune areas near Purisima Point. Purisima beaches are comprised of two monitoring segments, Purisima North (PNO) and Purisima Colony (PCO). PNO is characterized by sand sheets and sandy pocket beaches from the south end of SAN 1.3 miles to Purisima Point. PCO includes a fenced California least tern South beaches consist of five miles of continuous sandy coastline backed by dune habitat and steep bluffs. South beaches are comprised of three monitoring segments, Wall (WAL), Surf North (SNO), and Surf South (SSO). WAL section begins at the north end of Wall beach 1.3 miles south to Santa Ynez River mouth. On the north end there is a 0.25 mile “open area” used for military recreational access while the remaining portion is closed. SNO extends 1.8 miles south from Santa Ynez River mouth and consists vegetated foredunes with narrow beach fronts. This section contains 0.5 miles of “open area” used for public recreational access. SSO is a 1.9-mile section of narrow sandy beach with vegetated and steep bluff backs. Figure 3 illustrates the monitoring segments within the two beach sections along with the monitoring transect blocks described in Chapter 3.

Figure 2. Study Area – VAFB Beaches

Figure 3. VAFB Beach Monitoring Segments and Transect Blocks

1.3 Current Monitoring and Management Efforts

Annual plover monitoring at VAFB began in 1993 to estimate the annual nesting population and reproductive success. It was not until 2002 that a formalized protocol was developed to track and monitor the breeding population. Point Blue Conservation Science is currently working to document all nesting plovers on VAFB and determine annual trends in population. Researchers are particularly focused on documenting how nesting plovers are responding to restoration efforts as well as predator pressures.

1.3.1 Nesting and Distribution Monitoring

The VAFB plover population has been highly variable from year to year, with a mean population size of 248 adults and mean nest number of 359 nests from 2000-2018 (Robinette et al. 2018). USFWS measures reproductive success by the number of chicks fledged per male plover. However, at VAFB it is not possible to track chicks to fledge due to inconsistent banding efforts throughout the years. Therefore, managers at VAFB rely on tracking clutch hatch success to understand the trends in reproductive success. Like plover population size variability, clutch hatch success is also highly variable with a mean of 46% nests hatch per year. However, most years are either extremely below or well above this average.

Plover nest distribution has varied over the years. The mean number of nests initiated on North and South beaches is similar between 1994-2018 (Figure 4). Most recently, however, there has been a significant increase in the number of nest initiation on South beaches since 2014. Nest initiation increases often are due to years of high predations, such as the spike seen in 2004 where there was an increase in coyote nest takes and as a result an increase in re-nesting or triple clutches.

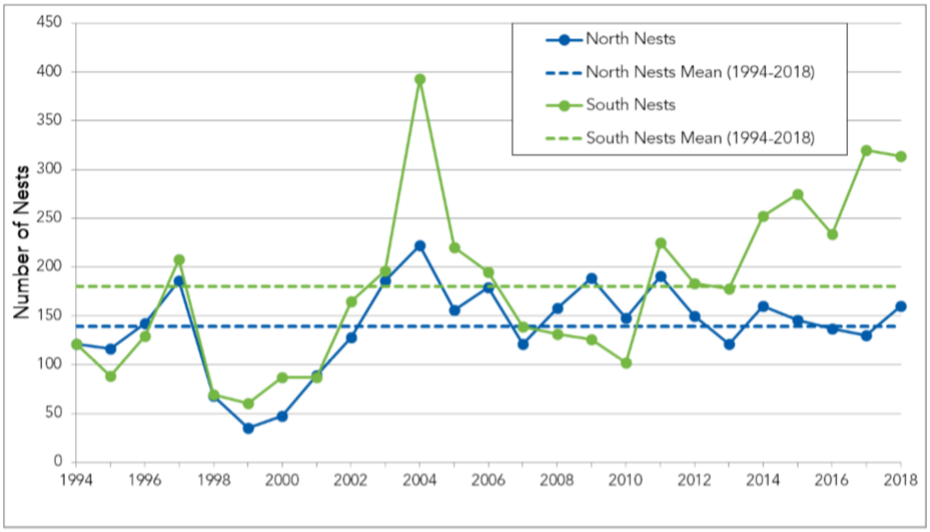

Figure 4. Trends in annual number of nests initiated for North and South beach from 1994-2018. Source: Robinette et al. 2018.

On the northern most section of North beaches (MIN-SHS), nest initiations have been declining since 2006 despite of habitat availability (Figure 5). As a result, most of the nesting on North beaches appears to be taking place in aggregated areas at SAN. One of the theories presented by researchers is that predator pressures are pushing plovers to nest in denser clusters and possibly regulating the size of the breeding population in that area. In 2011, a peregrine falcon eyrie (nest site) was established after decades of the peregrines being extirpated from VAFB (Robinette et al 2018). Peregrines are often seen hunting shorebirds (including plovers) on North beaches and are potentially having an impact on nesting. Another theory is the result of habitat loss at MIN, SHN, and SHS beaches.

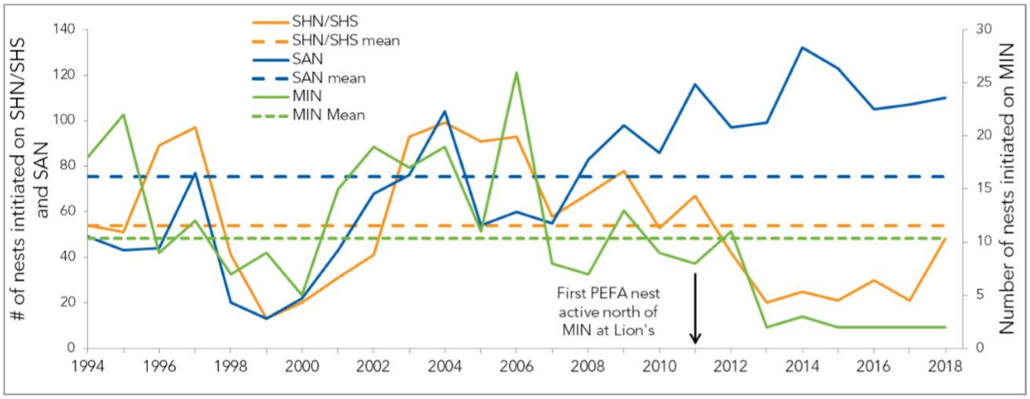

Figure 5. North Beach Nest Distribution for MIN, SHN/SHS, and SAN. Source: Robinette et al. 2018.

1.3.2 Predator Management

Poor clutch hatch success is largely due to predation of nests by two main nest predators: coyotes (*Canis latrans*) and common ravens (*Corvus corvax*). Common ravens have been a common nest predator throughout the range of the plover. However, it was not until 2004 that ravens were detected on VAFB and began taking plover nests on beach sections (Mantech 2009). This is believed to be due the expansion of the raven population into central California coastal territories (Boarman and Heinrich 1999) due to human activities which have provided food and habitat for ravens (Camp and Knight 1993; Boarman et al. 2006; Kristan and Boarman 2007). Ravens predated 10 percent of all initiated nests on VAFB in 2018, with the highest year on record being 2017 where ravens took 25 percent of all nests (Robinette et al. 2018).

Coyotes are known to predate nests primarily on South beach sections with the highest occurring in 2017 with 20% of all initiated nests taken by coyote (Robinette et al. 2017). Both predators are sought out for lethal removal by predator management contractors on VAFB prior to annual plover breeding season and continues until nesting is completed.

1.3.3 Habitat Restoration

VAFB initiated an extensive beach restoration management plan that aims in removing invasive species European beach grass, ice plant, and Sydney golden wattle. These species have a drastic impact on preferred nesting habitat of the plover by converting once open and dynamic habitat into stabilized, densely vegetated monocultures (USFWS 2007). The goal of the VAFB beach restoration plan is to transform these stabilized structures into natural plover habitat that provides larger areas for nesting, chick rearing, and roosting (SRS Technologies 2005).

Prescribed burning followed by herbicide treatment has been the preferred treatment strategy by restoration contractors. In 2007, restoration began on 800 acres of North beach at SAN and PNO breeding sections. In 2009, 70 acres were restored north and south of the Santa Ynez river mouth in the WAL and SNO breeding sections. Then from 2013 to 2015, this area was also contoured using heavy equipment to breakdown unnatural dune structures formed by the vegetation. In 2013, 180 acres were burned and treated in PCO section with annual follow-up herbicide treatments to regrowth. In 2014, VAFB began yet another restoration project on North beach in the sections of MIN. Thousands of pounds of chemical and millions of dollars have been used over the course of these projects with so far very minor to no significant increase of plover use for breeding (Robinette et al. 2018; Mantech 2018).

1.4 Research Objectives

Nesting occurs throughout the 10-mile coastline of VAFB with annual variation in distribution which appears to be dependent on level of nest predation and habitat quality (Robinette et al. 2017). Efforts to increase nesting success and population are focused on large scale habitat restoration and predator management. However, there has been no work conducted to determine where the most important areas or hot spots of plover nest initiation, clutch hatch success, or nest predation occur to implement these activities. In addition, not much is known about how other factors such as bottom-up influences of food availability within wrack deposits may influence nest establishment. The goal of this study is to inform managers where important nesting areas are and to provide additional information that can be used to redistribute management actions (restoration, beach closures or predator removal) to be conducted in hot spot areas. This will help in distributing funding wisely, refraining from "good faith" restoration in lieu of intentional restoration.

The scope of this study was to provide answers to the following research questions using 17 years of plover nesting data at VAFB:

1. Are there consistent temporal and spatial nesting hot spots in three categories: nest initiation, successful clutch hatch and clutch failure due to predation? What areas are key spots for focusing future predator management and restoration work?
2. Which beaches of VAFB have hot spots of plover nesting and do these areas correlate with recent habitat restoration activities? Have hot spot distributions changed post-restoration in these areas?
3. Is there a correlation between high wrack abundance and nest initiation or hatch?

I hypothesize that significant hot spots occur in central areas of the plover breeding areas and they will be highly concentrated near river mouths. Further, I hypothesize that a larger percent of nest initiations occurs during periods of high wrack abundance.

1.5 Document Outline

This study contains five additional chapters. Chapter Two begins with an overview of related research about plover nest distribution, predator management and wrack importance, and continues with an exploration of related literature regarding hots spot analysis and related field data management. Chapter Three explores the field collection methodologies of the data used for the analysis and how these methodologies can conflict with the analysts need. It demonstrates the process of teasing the data into a useable form for this analysis and further demonstrates the need for the use of a relational database. Chapter Four presents the methodology for data analysis. Chapter Five presents the results and finally Chapter Six presents the implications of the results, further recommendations, and future research suggestions.

Chapter 2 Related Research

Factors contributing to the nest site selection of the plover have been studied on several breeding grounds within its range. None, however, have been conducted at VAFB. Studies that analyze habitat mainly focus on microhabitat or specific substrate directly near the nest cup. Studies regarding spatial distribution of nests have been conducted in many locations as it relates to predators specifically, however no research was found analyzing the possible relationship between wrack subsidies and nesting. Habitat restoration within breeding ranges is well represented in the current literature. Impacts of restoration on plover nesting have been investigated at a few sites. However, no previously published research was found on spatio-temporal nest distribution using hot spot analysis. Below is a review of relevant studies related to this thesis involving spatial distribution, nest site selection, a restoration review, and wrack subsidies as it relates to shorebirds or plovers.

2.1 Nest Site Selection and Distribution

Nest aggregation and distribution of plover nests has been studied at the central and northern most edge of its range. In Northern California, Patrick et al. (2017) found that population density and nest aggregation had a strong correlation. At their site they found a large portion of suitable habitat was left unoccupied while the population seemed to breed in aggregated patterns and during years of higher populations plovers nested closer to one another. This study highlighted the need to examine nesting patterns within the center of plover breeding range where population size is larger to determine how the relationship between population size, suitable habitat and the degree of nest aggregation. The main difference between the breeding population used for this study and VAFB's population, is that all their birds are color marked. Meaning that they can distinguish each individual and as a result confirm all currently active nests. Although the number of adult plovers can vary annually, the breeding population in Northern California is relatively small (64) compared with VAFB population size (249) making VAFB an ideal study site for nesting distribution.

Saalfeld et al. (2012) analyzed spatial distribution and nest site selection variables in the inland population of plovers to determine nest characteristics involved in site selection to better inform habitat management. This study used logistic regression and kernel density estimation to identify habitat variables and to asses hot spots. They found that that over 57% of nests were located within 100m of the nearest active nest site and nearly all nests were located adjacent to an object such as a rock or plant. This suggests that nesting near an object may be chosen to protect the eggs during extreme weather events. This conclusion is in alignment with the findings of Page et al. (1985) who also analyzed nesting near objects and found a positive correlation between success and object placement.

Fahy's (2008) study of the breeding population at the Guadalupe Oil Fields just north of VAFB analyzed both micro habitat variables and nest distribution over time. Fahy confirms the above two studies' findings about nest placement near objects but also looks at the spatial distribution of nests. Analysis strategies focused on regression, generalized linear models and nearest neighbor methodologies. Fahy found that nest distribution varies over years from random to aggregated. The importance of Fahy's research to this thesis is that the population studied was just north of the VAFB population of snowy plovers and findings may be closely related to regional habitat influences.

Eberhart-Phillips et al. (2016) analyzed the spatial distribution of the entire breeding range of the snowy plover. They found that population growth in the southern regions were due to predator management and that negative growth was linked to nest exclosures and harsh winter conditions. This research also found that studies at the range-wide scale are misleading when region-specific mechanisms such as varying climate and management practices are at work that may impact the local breeding populations. They recommend that more studies be conducted on regional scales rather than larger metapopulation analysis such as theirs to aid in conservation and management of the species.

Another study was conducted at Mono Lake, a non-threatened inland population of the plover which found that nesting density is directly related to predator pressures (Page et al. 1983). Although Page et al. (1983) point out that food distribution has an impact on nest distribution, they do not directly look at the possible correlations between the two.

2.2 Plover Habitat Restoration and Research

Habitat restoration at VAFB is at the forefront of plover management. While no research was conducted prior to carrying out the removal of invasive plants and dune contouring at VAFB, follow-up monitoring has been ongoing since the restoration. Other breeding sites have already documented response of the plover to restoration and most have found a favorable response to restoration initially, however, if the areas are not consistently revisited for follow up treatment and contouring, nesting begins to decline in those areas as native plants begin to recolonize and dune systems are restored to natural slopes (Zarnetske et al. 2010). This has been observed at VAFB as well by current biologists (Robinette et al. 2018). Average mean nest density increased substantially following both contouring events (Figure 6) at WAL and SNO and this was followed by a decrease in nest initiation beginning in 2016 when native vegetation began taking over the recently barren ground created by the removing the dune structures (Robinette et al. 2018). Powell and Collier (2000) recommend continued evaluation of the restored nesting areas and cautions that it should not be based on the presence of nesting alone but tracking of productivity over time. This conclusion is based on restoration of a nesting site in San Diego county where factors contributing to increased use and reproductive success were found to be related to habitat quality, but this led also to subsequent predation pressure in the restored areas. Determining if there is any correlation in the distribution of initiated nest hot spots pre- and post-restoration at VAFB is analyzed in Chapter 5.

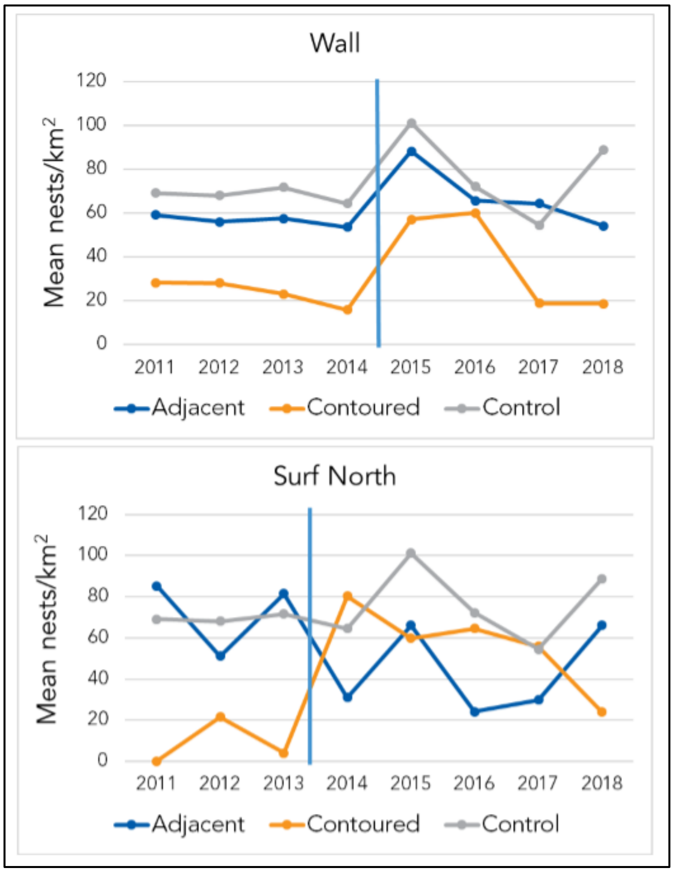

Figure 6. Relative mean nest densities on Wall and Surf North in the contoured areas, the adjacent beach immediately west of the contoured areas, and all South beach south of Surf Open Area (control) from 2011-2018. The vertical line represents when dunes were contoured. Source: Robinette et al. 2018

Zarnetske et al. (2010) analyzed plover response and non-target species response to restoration. They found that plover nesting success following the reduction of European beachgrass can occur initially but sustaining this increase may be possible only after repeated treatments or contouring of dunes. Within the first year of restoration, there was increased nesting, however in the following years, numbers of nests decreased unless the habitat was actively managed yearly. It appears that plovers responded to the initial removal of vegetation and the overall bare ground. Caution is given from this research that the single species approach to restoration will increase target species population but may have long term potentially negative impacts on other species and ecosystem functions.

Nelson (2007) found that breeding habitat may not be the limiting factor in plover breeding population in Humboldt county. Conspecific attraction or social cues of plovers may be more important to colonizing a breeding area rather than habitat restoration or removal of beach grass alone. Therefore, the success of restoration that is focused on increasing plover productivity and promoting plover recolonization is halted if the site itself is unoccupied by other individuals. In addition, this study also found that plovers may choose a nest location not based on habitat but based on the distance to active nests.

At the same study site, Leja (2015) looked at nest site selection and plover nest establishment in areas where habitat restoration had occurred. This study found that in general, plovers nested more frequently in restored habitats than unrestored habitats with 84 percent of nesting occurring in these restored habitats. Restoration mimicking the natural dune processes with yearly follow up were favored. Beach slope and width were the two physical habitat characteristics that correlated with increase nesting at sites. Gentle slopes and wider beaches may provide great visibility for the onset of predators, increasing nesting survival. The research produced concrete management recommendations for future restoration such as no more than 4% slope and beach width greater than 120 meters. In addition, the study found that the attraction to nesting sites is heavily correlated with the presence conspecifics (other pairs of breeding plovers). Social attraction may increase nest site selection and nesting densities in areas where there are other plovers compared to physical habitat and restoration alone. Leja (2015) cautioned managers that restoration alone may not attract plovers therefore careful consideration to locations is vital for the success of any habitat restoration.

The overall take away from the literature regarding habitat restoration, is that human induced restoration is successful in increasing plover nesting if it is continued over time and site selection is based on the presences of neighboring conspecifics. Physical changes to habitat alone, does not guarantee the use of the area by nesting birds.

2.3 Wrack Importance for Shorebirds

Sandy beaches around the globe rely on the input of macroalgae and seagrass accumulations that support terrestrial macrofauna by increasing food availability and habitat structure (Dugan et al. 2003; Ince et al. 2007; Schlacher et al. 2017). This ocean subsidy, or wrack, supports terrestrial invertebrates which are often the center of the sandy beach food chain (McLachlan and Brown 2006) by providing prey resources. Wrack has been directly correlated with the distribution and abundance of shorebirds, including plovers, on sandy beaches throughout the literature (Dugan et al. 2003; Brindock and Colwell 2011; Lafferty et al. 2013; Dugan et al. 2003; Schlacher et al. 2017).

One of the most significant studies analyzing how macrofauna communities associated with macrophyte wrack influence the abundance and spatial distribution of shorebirds is a local Santa Barbara county study headed by Jenny Dugan et al. (2003). This study surveyed 15 beaches using transects to collect wrack samples and count shorebird species. They found that increased wrack accumulations were positively correlated with macrofaunal abundance and the number of plovers was found to have positive correlation to the amount of standing wrack.

There are few studies that analyze the correlation between wrack and plover abundance. The studies that have been conducted occurred during the non-breeding season when plovers are in wintering flocks. All show a positive correlation between wrack abundance and invertebrate species abundance as a result a positive correlation between plover or shorebirds and wrack abundance (Dugan et al. 2003; Lafferty et al. 2013). The assumption made in this thesis is that large abundance of wrack provides and increased abundance of macro-invertebrates. In this thesis wrack is explored as it relates to abundance during nest initiation.

Chapter 3 Data Collection and Management

The ability to share and conduct an analysis with data collected from researchers in the field relies on the ability to "read" the data that are in a standardized format. Often data collection and management are geared first to the field researchers needs and the results are not always user friendly on the back end for future analysis. This chapter looks at the plover data sets acquired for this study, the progression from data cleanup, data aggregating to processing, and to a final dataset used for the analysis in this thesis. The last section discusses a conceptual model of a relational database for all plover data for future archiving and analysis.

3.1 Field Data Collection Methods

Field collection of plover data has remained relatively consistent since 2002 when VAFB began intensive monitoring of the breeding population. The same basic nest data have been taken, however, over the years an increased amount of data have been collected in the field for various research projects. Protocols for data collection in the field and the way they are archived or the format they are entered, have been focused primarily from the field biologist perspective. Real time data of nests status and estimations of hatch dates are calculated on the fly using the data collected each day. This is done so that biologists can track nests throughout the incubation period and birds throughout the breeding season. Therefore, formatting for data sharing is not currently the priority in plover data management.

3.1.1 Data Sources

Spatial data, imagery, and spreadsheets of raw data were gathered for this thesis from VAFB and Point Blue Conservation Science. A non-disclosure document was required to procure the data from the Air Force and special permission to use data for this thesis was given by Asset Management. Details of the data gathered are represented in Table 1.

Table 1. Summary of Data Received

Dataset	**File Type**	**Data Type**	**Details**	**Source**
2002-2010 Plover Nests	Worksheet	Point	Nest location and attribute data	VAFB
2011-2018 Plover Nests	Worksheet	Point		
Plover Breeding Habitat	Shapefile	Polygon	Boundary habitat	
2011-2018 Wrack Data	Worksheet	Polygon	Wrack index data	Point Blue
Transect Block	Shapefile	Polygon	Outlines transect blocks	

3.1.1.1 Transect Block Surveys and Wrack Data

Transect block surveys began in 2012 by Point Blue Conservation Science and are conducted each week during the breeding season. Each beach section described in Chapter One is broken down further into transect blocks illustrated in Figure 3. Blocks are approximately 100-300 meters in length along the coastal strand and extend the width of the beach from the current high tide line during the survey day to the foredune. A transect in biological surveys, usually refers to a linear segment where counting of plant and animal species are done on intervals along a line in thin or thick bands (Montello and Sutton 2006). The transects in this study are arranged as linear bands referred to as “blocks” and the areas within is where sampling occurs. The transect block surveys are conducted on each beach section once per week throughout the plover breeding season. Biologists walk down the beach counting the number plovers and other avian species within each block, documenting the presence or evidence of terrestrial nest predators, and recording the abundance of wrack present on the beach. Each transect block is given a single value that estimates wrack abundance in the form of an index. This index ranks wrack presence on a scale from zero to five: zero indicates there is no wrack present and five indicates heavy deposits within the last high tide line.

The data files for these surveys contain several attributes: date, monitor, transect block name, predator evidence, wrack index value, the number and type of plover or other avian species present. Data are entered by field biologists in multiple tables which include all survey years. Tables 2-4 include a sample of the transect data received for this project. Although data in Tables 3 and 4 were not used for analysis in this thesis, they are shown here to demonstrate the fragmentation of the data and need for long term storage without duplication in records. This is discussed in Sections 3.1.2 Data Quality Assessment and 3.2 Conceptual Relational Database Design.

Table 2. Extracts of Transect Survey Data Spreadsheet Predator and Wrack

Survey Date	**Monitor**	**Transect Block**	**Pig Tracks**	**Coyote Tracks**	**Raccoon Tracks**	**Wrack Index**
8/6/2014	JKM	Cobble	No	Yes	No	1
8/6/2014	JKM	Trex	No	Yes	No	1
8/7/2014	LAH	Border Trail	No	Yes	No	0
8/7/2014	LAH	Pebble	No	No	No	2
8/7/2014	LAH	GrandCyn	No	No	No	2
3/10/2015	JKM	SHSend	Yes	Yes	No	1
3/10/2015	JKM	Arrowhead	Yes	No	Yes	0.5

Table 3. Extracts of Transect Survey Data Spreadsheet Avian Species

Survey Date	**Monitor**	**Transect Block**	**Avian Species**	**Count**	**Sex**	**Age**	**Behavior**
8/6/2014	JKM	Cobble	WEGU	2	U	U	U
8/6/2014	JKM	Trex	CAGU	25	U	U	U
8/6/2014	JKM	Trex	WEGU	15	U	U	U
8/7/2014	LAH	Pebble	GBHE	1	U	U	tracks
8/7/2014	LAH	GrandCyn	GBHE	1	U	U	U
8/7/2014	LAH	GrandCyn	WEGU	1	U	U	U
3/10/2015	JKM	SHSend	MERL	1	U	A	Flushed plovers
3/10/2015	JKM	Arrowhead	RTHA	1	U	A	Flying

(U-unknown, A-Adult, WEGU-western gull, CAGU-California gull, GBHE-great blue heron, MERL-merlin, RTHA-red-tailed hawk).

Table 4. Extracts of Transect Survey Data Spreadsheet Plover Observations

Survey Date	**Monitor**	**Transect Block**	**M**	**F**	**U**	**Pair**	**Chicks**	**Juvenile**
8/6/2014	JKM	Cobble	1	2	0	1	0	0
8/6/2014	JKM	Trex	4	3	1	2	0	1
8/7/2014	LAH	Pebble	1	0	0	0	3	0
9/7/2014	LAH	Pebble	2	1	1	1	0	0

(M/F- male or female plover, U- unknown sex, Pair-two plovers confirmed as breeding adults)

The main issue with the data in these tables is that many of the attributes repeat, such as the survey data, monitor, and transect block. It is difficult to see from the different data files how these data relate to each other. In addition, the wrack index data needed for the analysis in this thesis are organized by survey date, not by transect block. Determining how to format this data to make it useable was the first step in the process, followed by cleansing the data.

3.1.1.2 Nest Point Data

Each point represents a nest established in any given breeding season. Each beach section is surveyed a minimum three days per week by plover biologists for the presence of active nest sites and breeding birds. When a nest is located, the biologist records the GPS location, transect block, and number of eggs. GPS accuracy ranges from 3-5 meters. Each nest is monitored until it has hatched, predated or failed. An estimated initiation and fate date are added to the GPS attribute file categorizing the nest as hatched, predated or failed. Failed nests are recorded when a nest is washed out by tide, buried by sand due to wind, or nest abandonment. Nests are recorded as predated when the nest fails prior to hatch date and there is evidence of predation at the nest such as tracks or eggshell fragments.

Nest point data were acquired for monitoring years 2002 to 2018. Each nest was given a number following the acronym for each beach section. The data were collected by two research contractors who recorded and archived the data in different formats impacting data cohesiveness for analysis. From 2002 to 2010 Mantech SRS collected data without the use of transect blocks and stored by year in individual excel spreadsheets and received as annual shapefiles (Table 5). Data spanning from 2011 to 2018 were collected by Point Blue Conservation Science and received in one excel file (Table 6). It was during this period when transect blocks were created and added to the attribute fields.

Table 5. Nest Point Data Sample from 2002-2010

Nest ID	Latitude	Longitude	Initiation Date	Eggs	Hatch Date	Fate Date	Fate	Cause
MM-01	34.8501970	120.6097910	4/5/2004	1		4/9/2004	Destroyed	Tide
SA-104	34.7828950	120.6268440	7/4/2004	3	8/4/2004			
SHN-02	34.8418870	120.6103910	4/5/2004	3		4/21/2004	Predated	Raven
SHS-19	34.8213360	120.6149190	6/2/2004	1		6/4/2004	Predated	Coyote
SN-024	34.6717140	120.6100130	4/7/2004	3	5/7/2004			
W-02	34.6998020	120.6018700	3/29/2004	1		3/31/2004	Failed	Unk
SS-083	34.6580670	120.6152170	6/2/2004	3	7/3/2004			

Table 6. Nest Point Data Sample from 2011-2018

Nest ID	N_UTM84	S_UTM84	Transect Block	Eggs	Initiation Date	Fate Date	Fate
11MIN001	3859182	718654	Alligator	1	5/10/2011	5/10/2011	Hatched
11SHN006	3857952	718628	Scaffolding	2	4/25/2011	5/5/2011	Abandoned
11SHS016	3855970	718149	SHSstart	3	5/6/2011	5/20/2011	Tide
11SAN021	3852201	717424	Stix	3	4/10/2011	4/28/2011	Raven
11SNO047	3840279	719242	NSurfopen	2	5/25/2011	6/21/2011	Hatched
11SSO027	3838207	718683	Squid	1	5/01/2011	5/24/2011	Coyote
11WAL042	3841770	719666	Cigar	3	5/25/2011	6/26/2011	Hatched

3.1.2 Data Quality Assessment

Most of the data received for this thesis required extensive processing prior to analysis due to poor data quality and inadequate formats. The 2002-2018 nest data was in two formats due to two organizations collecting and archiving data differently. These two datasets, represented in Table 5 and 6, contained redundant data in different representations and needed to be standardized and consolidated for integration into one file. Attribute headings in these tables are inconsistent, nest identification numbers differ, nest coordinates are in different projections and there is no transect block information in 2002-2010 dataset (Table 5). Prior to integrating these files, all data needed to be “cleaned” which is a process using strategies to check values, fix data anomalies, remove duplicates and validate data.

3.2 Data Cleanup

The process of data cleansing targets errors in the data or anomalies in the data that are determined by the specific application of use or analysis and requires an expert in the field the data is taken (Muller and Freytag 2003). It is especially needed when there are two data sources that require integration (Rahm and Do 2000; Kandel et al. 2011). In this case, it would need to be a biologist involved with plover conservation that understands the vernacular within plover ecology thus the data cleansing was conducted by myself. While many large datasets use programming, frameworks designed to clean data (Muller and Freytag 2003; Lee et al 2000), plover data cleaning strategies were conducted for this thesis using excel filters, pivot tables, and sorting functions. The outcome was an integrated plover nest data source applicable for use in this thesis and capable of being uploaded to ArcGIS for analysis.

Figure 7 represents the conceptual model of data cleansing used in this thesis provided by Lee et al. (2000). The first step was to sort through both datasets and clear up any duplicate records, differences in spelling, categorical data values and attribute headers in all datasets. Following this data cleansing model by Lee et al. 2003, both nest datasets and the transect data underwent an enormous restructuring and manipulation to integrate all into one useable file for analysis. Figure 8 depicts the model for data cleansing for this thesis and specific steps are described in Sections 3.2.1 and 3.2.2.

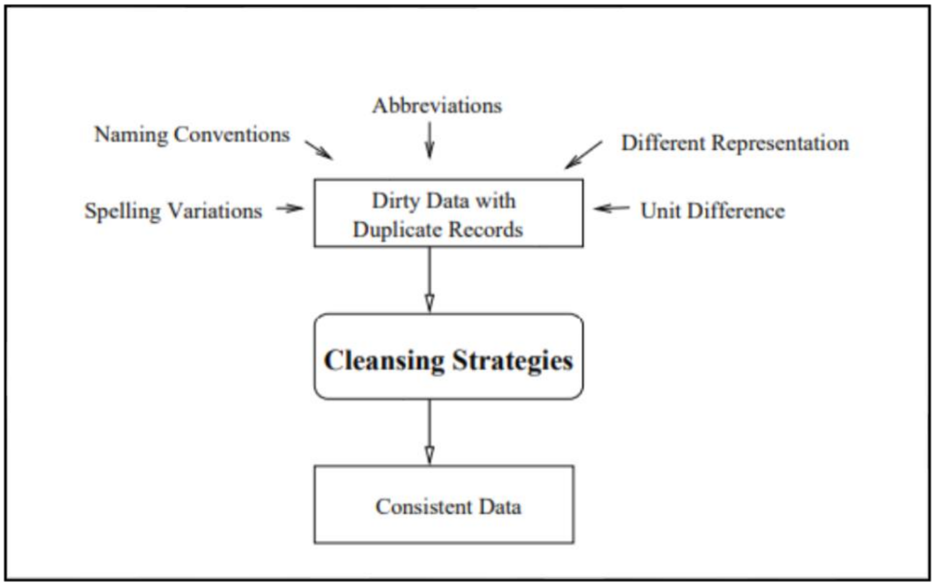

Figure 7. Data Cleansing Conceptual Model. Source: Lee et al. 2000.

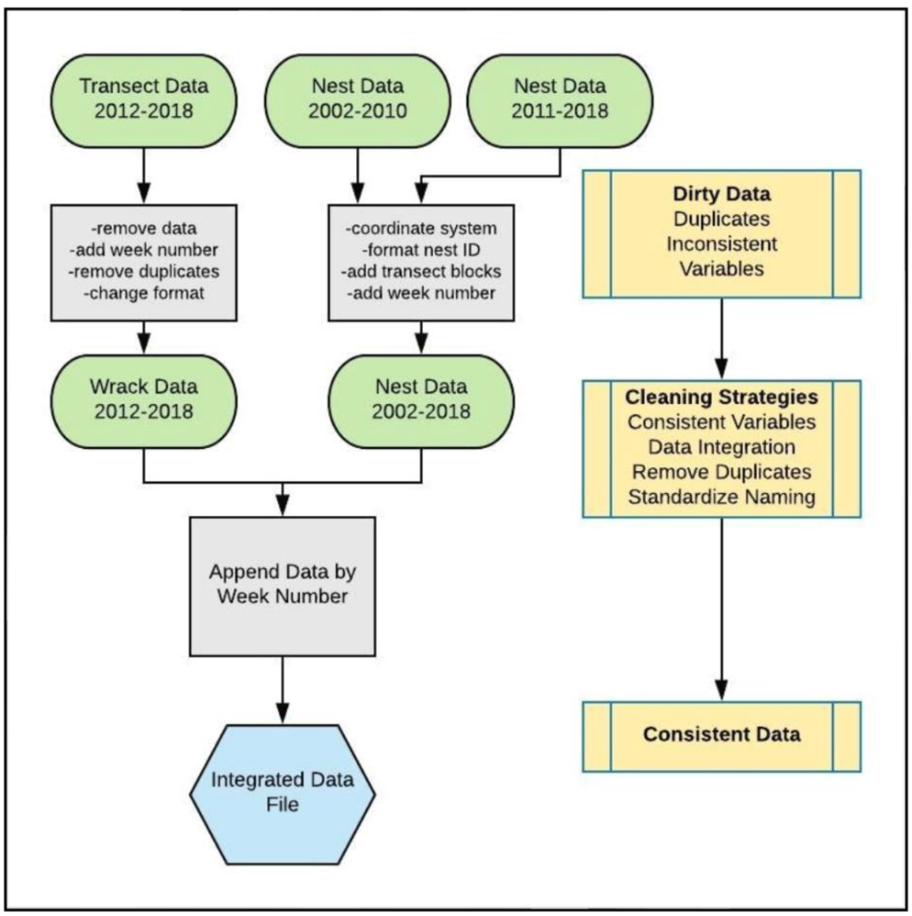

Figure 8. Nest Data and Wrack Data Cleansing and Integration Workflow

3.2.1 Nest Data Processing

The data formatting used here followed the basic structure shown in Table 6; therefore the 2002-2010 data underwent the most manipulation to fit into the basic format of the 2011-2018 dataset. First the projection of the 2002-2010 data set was changed in ArcPro and exported into another excel file for further processing. Each of the nest names was converted into the "Year – Beach Section – Nest number (18SAN052)". Categorical values for nest fate were examined and put into two fields "Fate" and "Fate Date". These values were sorted to remove spelling errors and inconsistent nomenclature. Data attributes were added to the 2002-2010 data to match the 2011-2018 data. These attributes included: year, beach segment and transect blocks. Finally, the nests were given a week number that refers to the calendar week of the specific year in which it was initiated. The week number serves as a key to be used to append the wrack data file.

3.2.2 Wrack Data Processing

Prior to using the transect data files (see Tables 2-4) for analysis, three steps of data cleaning and integration were required. First, since this dataset included information on shorebirds and predator observations, in addition to wrack data, for each transect, these fields were removed to create a file that contained only wrack data. Then new data variables were added: week number, year, beach section, and monitoring segment. By adding week numbers and removing the individual survey dates, this data can "speak" to the nest data described above by linking it with week numbers. In addition, repeated transect blocks were eliminated so that each year had only one row for each transect block. Week numbers became columns and wrack values were added to the columns along each transect block row (Table 7). Next this information was used to assign a wrack value to each nest initiated in corresponding transect blocks. This value was appended to the nest point data file. Appendix A contains an extract of the new integrated datafile which includes both nest information and wrack value assignment per nest.

Table 7. Extract of 2014 Wrack Data Week Formatting

Year	Beach Section	Monitoring Segment	Transect Block	Week 10	Week 11	Week 12	Week 13	Week 14	Week 15
2014	North	SHS	OJ	4.0	2.0	1.0	1.0	0.5	1.0
2014	North	SHS	Bottlebuoy	3.5	2.0	1.0	1.0	1.0	0.5
2014	North	SHS	Mole	3.0	1.0	0.5	1.0	0.5	0.5
2014	North	SHS	Bottlelog	4.0	1.0	0.5	0.5	0.5	0.5
2014	North	SHS	Trilog	3.0	1.0	1.0	1.0	1.0	0.5
2014	North	SHS	SHSend	2.0	2.0	1.0	1.0	1.0	1.0
2014	North	SAN	Arrowhead	1.5	1.0	1.0	1.0	1.5	1.0
2014	North	SAN	L13buoy	1.0	1.0	1.0	1.5	2.5	1.0
2014	North	SAN	Niceperch	1.0	1.0	1.0	1.5	2.5	1.0

3.3 Conceptual Relational Database Design

A relational database is a set of tables containing data that are related to each other. Each row in a table is labeled with a unique id that is called a “key” that links each table to one another and determines their relationship to each other. Data consistency is maintained in the relational database structure and allows for multiple users to access the same data in different formats or queries. The benefit of this type of data structure is that less time is needed for data management and data can be used for multiple analyses.

The complete plover nest data assembled through data cleaning and integration required an extensive amount of time to create. If at the onset, these data had been stored in a relational database, simple queries could have been performed to end up with the complete plover nest dataset shown in Appendix A. Although current plover biologists use a Microsoft Access database, the design of the database was not available for this project and not appropriate or set up for the type of queries needed to aggregate data for this thesis. The structure of the Microsoft Access database was designed for the field biologists to enter data using forms and to develop queries for daily monitoring such as lists of nests that are due to hatch for that survey day. This "on the fly" data query capability is ideal for the field biologist but is not ideal for the data analyst. This Access database is also not complete, as it only includes data from 2011 to 2018 (the years when Point Blue had the monitoring contract). As a result, data were exported from this database and provided by Point Blue Conservation in Excel spreadsheets. Ideally, a relational database containing all years of nest data, from 2002 to 2018, would be set up so that information would not be duplicated, and a vast array of queries could be run to allow for various ways of aggregating the data for different analyses.

While processing data for use in this thesis, it became apparent that the creation of a relational database that could be used to extract the data tables needed for analysis is greatly needed. The effort used to deconstruct, clean, and integrate all the data used in this analysis would have been significantly reduced if there had been one location where these data were archived. It is now possible to create a plover relational database for future use after having processed all the historic and current data from both VAFB, ManTech, and Point Blue Conservation Science. Although this thesis did not create or populate a relational database, Figure 8 presents the proposed conceptual database design diagram of a relational database that would suit this type of data and further analysis. There is no duplicate data within this database and each category is kept separate in order to relate or query information together.

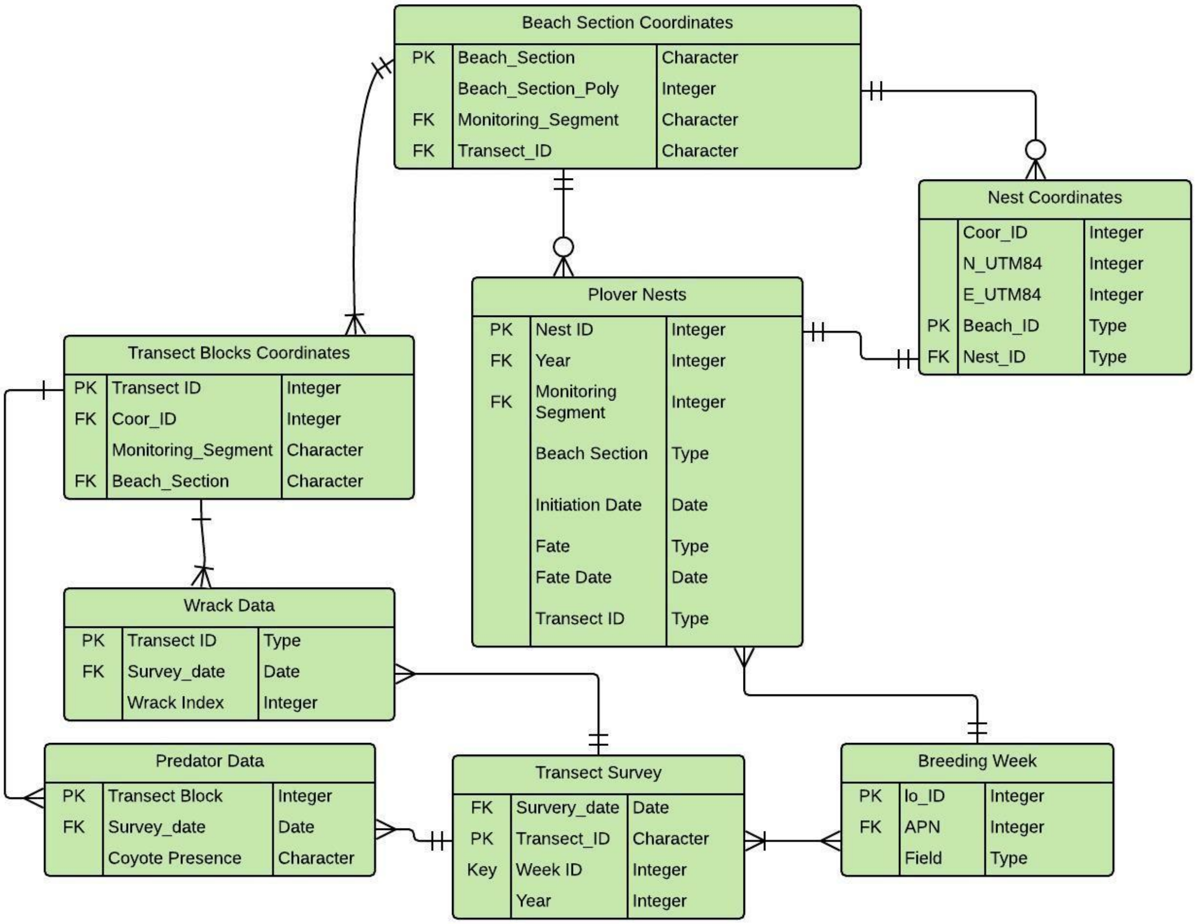

Figure 9. Conceptual Plover Relational Database

A large part of the time spent on this thesis work was manipulation and cleansing of existing data from multiple sources. Once the data were in an appropriate format, analysis could begin using the complete and integrated 17-year nest data including wrack information. The following chapters describe the analysis and results.

Chapter 4 Data Analysis

The purpose of this study is to assess the beaches of VAFB for plover nesting hot spots and make preliminary assessments of how wrack impacts nesting sites. The 17-year dataset of nest locations on VAFB provide an opportunity to analyze both spatial and temporal patterns of areas that are consistently used for nesting, to identify where successful nesting occurs and to determine locations with hot spots of nest predation. First, this chapter describes the different variables used in the spatio-temporal analysis using hot spot analysis, space-time tools and emerging hot spot analysis in ArcGIS Pro. The second part of the chapter describes the wrack data exploration to determine any correlation between wrack and nest initiation.

4.1 Plover Nesting Sites Analysis Methods

To analyze VAFB nesting, data from North and South beach were analyzed separately due to the geographic isolation of each segment and habitat differences. Each year of nest points was separated into three categories for both North and South beach: initiated, hatched, and predated nests. Two methods were used to identify spatio-temporal hotspots. The first analyzed each plover nesting year separately in two-dimensional analysis. The second used a three-dimensional data structure, a space-time cube, to organize all 17 years of plover nest data, followed by an emerging hot spot analysis using the input cube. The parameters chosen for these tools are crucial to the way these data were analyzed and dependent on the question being asked. In this analysis, parameters were used based on the plover breeding ecology where possible and they are described in each section below.

4.1.1 Annual Hot Spot Analysis – 2D

Hot spot analysis (HSA) is a test for randomness in data and identifies locations of statistically significant hot or cold spots by, first, aggregating point locations into polygons or grids, called features, generally weighted simply by the number of points in each area. It uses the Getis-Ord Gi* statistic to assess the weight of each feature within the context of the weights of features in its neighborhood (Getis and Ord 1992) and against the average weights of the study area. If the neighborhood has a weighted value that is significantly higher than that of the study area, then the feature is a hot spot. If the neighborhood value is significantly lower than that of the study area, then it is a cold spot.

The Gi* statistic in ArcGIS Pro, returns a number for each feature in the dataset as a z-score and p-value. Positive z-scores mean that it is an area of intense clustering or a hot spot. Negative z-score values indicate low clustering or cold spots. Lower p-values indicate high confidence that the pattern is different from random (Figure 10).

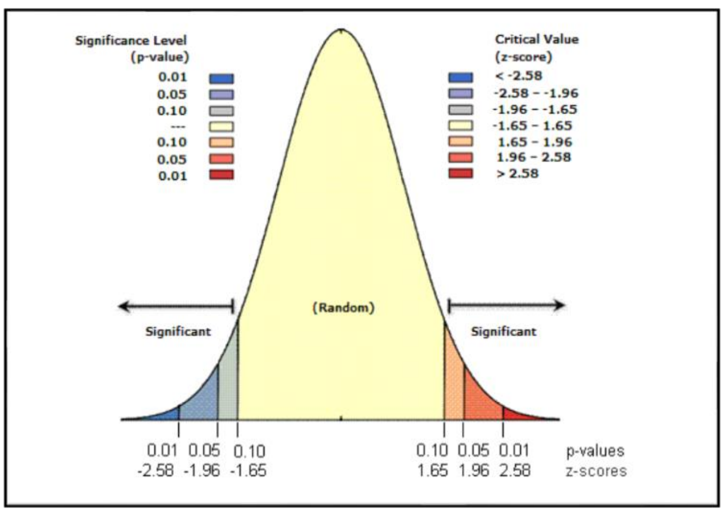

Figure 10. Standard normal distribution of p-value and z-scores for 90%, 95%, and 99% confidence levels. Source: Esri 2018a.

Figure 11 shows the workflow of data preparation for the annual HSA. Each year of the full 17-year plover nest data was extracted and then separated into the two beaches and those were again separated into the three nest categories. The result is 102 separate shapefiles disaggregated by year, beach and category. Each of these shapefiles was subjected to an HSA, resulting in 102 hot spot shapefiles.

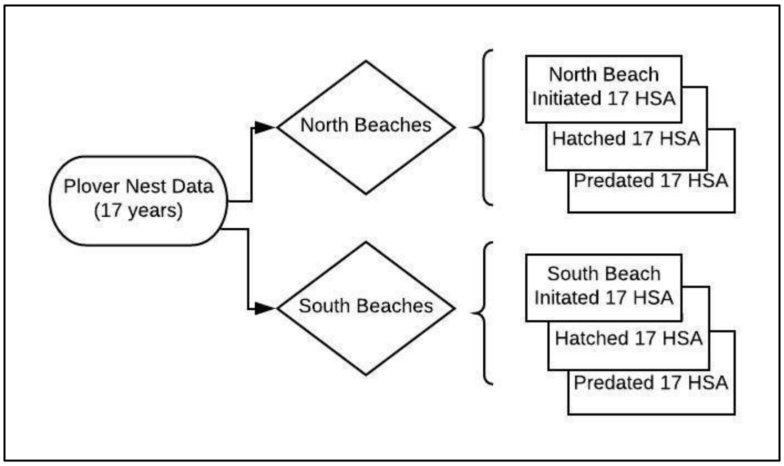

Figure 11. Workflow of data preparation for the HSA. Annual data were separated into North and South beaches, then into three categories: initiated, hatched and predated nests.

Two distance parameters are required when running the hot spot analysis tool: distance band and the size of the aggregation grid. Parameters were set using plover behavior and nesting preferences cited in current literature (Table 8). The fixed distance band or neighborhood is the distance the tool will use to determine which features are neighbors of each feature of interest. This was set at 100m based on published literature that shows nearest nest neighbors are generally located within 75-100m of the nearest active nest site (Saafeld 2012; Patrick et al. 2018). In addition, this is the distance of the average transect block and the average distance a plover would be disturbed off a nest when a biologist was sighted (Butala unpublished data). This distance (75-100m) does not represent territory size; territory size is the distance surrounding an active nest that a plover will defend as described below.

Table 8. Hot Spot Analysis Tool Parameters

HSA Paremeter	Description	Setting	Reason
Fixed Distance Band	Neighborhood	100m	Plover nest average nearest neighbor (Patrick et al. 2018)
Grid Shape	Shape	Hexagon	Less distortion, suited for neighborhood analyes
Aggregating Grid Size	Size of the Hexagon	20m	Plover average nesting territory (Fahy 2008)

The parameter for the shape of the aggregation grid used was hexagons. There were two choices for grid shape: fishnet (square) or hexagon. The hexagon grid was chosen rather than a traditional square grid because it reduces edge effects, there is less distortion, and conducting neighbor analysis between hexagons is more straightforward as the centroid of each neighbor is equidistant from other hexagon neighbors (Birch et al. 2007). In addition, the study site has irregular shapes along the coast and the hexagon grid fit the irregular pattern better, reducing edge effects. The dimension used was 20m to reflect the plover nest territory size (Fahy 2008). These parameters remained consistent when running all 102 models. All possible nesting area was included which extends to all sandy beaches of North and South beach.

While it did not form the basis of the final analysis in this study, the results of the annual HSA were useful in visualizing pre- and post-restoration nesting hot spots at WAL and SNO. Because restoration in these areas was based on increasing nesting and success, only initiations and hatch categories were analyzed. Maps of the two restoration sites were created from 2003-2018 initiated and hatched nesting hot spots.

4.1.2 Space-time Cube and Emerging Hot Spot Analysis – 3D

A space-time cube (STC) is created using an input data layer of time-stamped points that is restructured into a Network Common Data Form (NetCDF) data cube file using “create space-time cube tool” in the Space Time Pattern Mining toolbox in ArcGIS. NetCDF is a data format for multidimensional scientific data that is structured so that it is easy to access and display selected attributes through a dimension such as time. An STC is made from NetCDF data for a specific attribute dimension such that time stamped features are aggregated into space-time bins (Esri 2019) where the x and y (horizontal) dimensions represent space and the t (vertical) dimension represents time (Figure 12). Each bin has a fixed position in space (x,y) and in time (t). The temporal data are set up with time-steps while the spatial extent of the cube is represented by rows and columns (Figure 13) in a gridded pattern. In this analysis, the time-stamped points used as input are nest points from 2002-2018 shapefile.

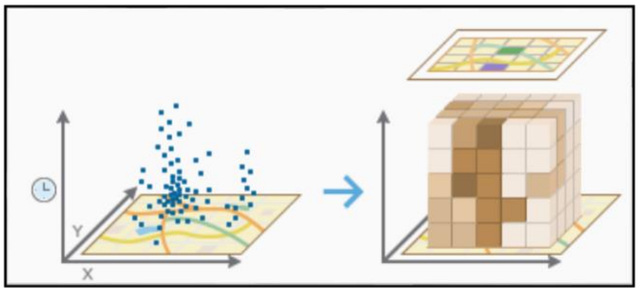

Figure 12. Aggregation of data points into space-time bins. Source: Esri 2018a.

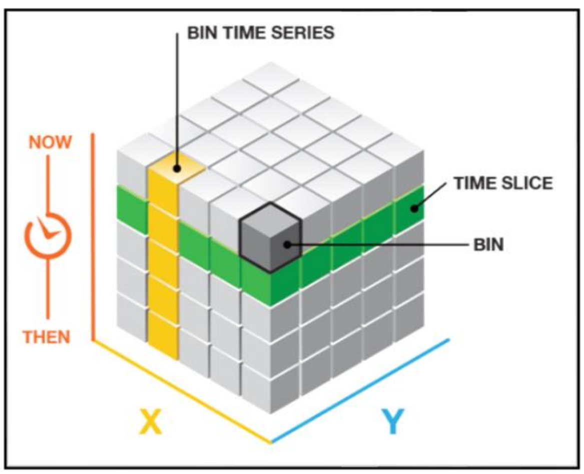

Figure 13. A space-time cube. Source: Esri 2018a.

Three separate STC's were created from the VAFB 2002-2018 plover nest data: all nests, successful clutch hatch and predated nests. There are several parameters that are optional for this tool, not all were used for this analysis. Parameters specific for this analysis are shown in Table 9; these include time-step interval and distance interval (size of bins). All other parameters were left at default or not used when tool was run. The time-step interval is used to determine how to partition aggregated points across time (years, months, weeks, days or hours). This was set at one year while the distance interval or size of the hexagon bin was set at 50m. Initially this distance was set at 20m to mimic the setting for annual HSA which represents a plover nest territory size (Fahy 2008). However, this proved to be too small and created a high frequency of zero counts in bins which made it difficult to detect trends (Esri 2018a). On the other hand, if it is set too high, the underlying pattern will be lost. After experimenting with this setting, 50m was determined to fit the best with the data. Nest points that share the same space and time-step interval were aggregated by the tool into hexagon bins with a one-year time step creating 17 time-steps in the plover cube. Although the nest data is limited to the breeding season only from March-September annually, the tool recognizes the other months as null values. The three space-time cubes generated were then used in EHSA to create hot spot maps and STC hot spot visualizations to analyze the distribution of hot spots annually.

Table 9. Space-time Cube Tool Parameter Settings for Analysis.

STC Parameter	**Setting**	**Description**	**Reasoning**
Time-step Interval	1 year	Aggregates points across time	Study is analyzing yearly plover nesting
Size of Grid	50m	How large the space-time bins	Closest to 20m territory without losing data
Bin Shape	Hexagon	Shape of Bin	Less distortion, better when using neighborhood analyses

The emerging hot spot analysis (EHSA) tool is an offshoot of hot spot analysis that uses an STC to calculate the Getis-Ord Gi* statistic to determine if each bin is a statistically significant hot or cold spot. From this evaluation, each bin is then given a z-score and a p-value. Hot or cold spots are a result of larger positive or negative z-scores. Lower p-values indicate a higher confidence that the pattern is not resulting from random chance.

Once hot spots are identified with the Getis-Ord Gi*, the Mann-Kendall statistic evaluates hot and cold spots through time within each stack of bins in the space-time cube (Mann 1945, Kendall and Gibbons 1990). The bin value in a stack is compared to the bin values at temporally adjacent positions. A +1, 0 or -1 value is assigned to each time period/bin. For example, if the first bin is smaller than the second it gives a +1 score. If the first bin value is larger than the second, it gives a score of -1. If there is no difference a value of zero is given. The results of each pair of time periods are summed and statistical significance is determined by evaluating this sum of the stack compared to the expected sum of zero.

As illustrated in Figure 14, combining the hotspot and trend z-scores and p-values for each stack of bins, the EHSA tool classifies each location as one of 17 categories (Esri 2018b). Since the full set of 17 categories is not relevant in this analysis, the description of each category is provided in Appendix B for reference. The description of the seven categories relevant to this study as provided in the next chapter.

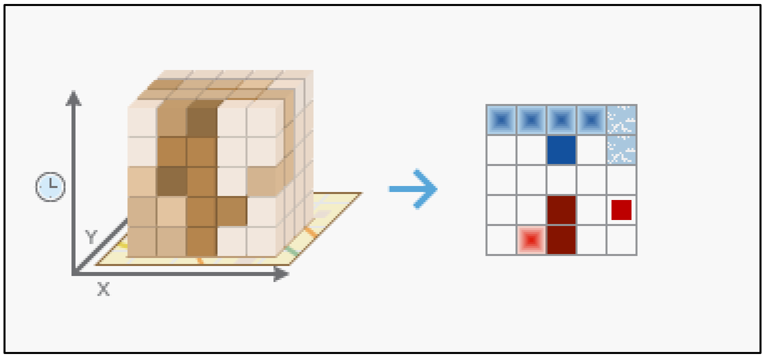

Figure 14. How Emerging Hot Spot Analysis Works. Shows a representation of an STC and resulting EHSA. Red represents hot spot categories while blue represents cold spot categories. No color indicates that there is no pattern detected. Source: Esri 2018b.

The specific parameters used for this EHSA analysis were neighborhood distance, neighborhood timestep, conceptualization of spatial relationships and polygon mask or area of analysis (Table 10). The neighborhood distance, the distance used to determine neighboring bins, used in this analysis was 75m which is based on the plover nesting nearest neighbor in the literature (Saafield 2006; Patrick et al. 2018). The polygon mask that was used was the shapefile of all possible plover breeding areas on VAFB. The neighborhood timestep was set at 1 and the spatial relationship was set at fixed distance. The time-step interval determines which features are analyzed together to assess space-time clustering. The conceptualization of spatial relationships parameter determines how spatial relationships among bins are defined. In fixed distance, each bin is analyzed within the context of the neighbor bins, those outside the neighborhood distance have no influence on the target bin’s value those inside the distance exert influence on the target bin.

Table 10. Emerging Hot Spot Analysis Parameters

EHSA Parameter	Description	Setting	Reasoning
Neighborhood Distance	The extent of the analysis neighborhood.	75m	Plover nest average nearest neighbor 75-100m (Patrick et al. 2018)
Conceptualization of Spatial Relationships	Defines spatial relationships among bins. Those outside neighborhood distance receive weight of zero.	Fixed Distance	Keeps the analysis within the neighborhood distance setting. Those outside are not included.
Polygon Mask	Defines the analysis study area.	Breeding Beach Polygon	This is the study area
Grid Shape	Determines shape of the aggregation bins.	Hexagon	Less distortion, better when using neighborhood analyses

Figure 15 shows the workflow from three STC and the analysis extent set in ArcGIS Pro for North and South beaches. Six shapefiles were created then displayed on maps broken into beach and beach segments for analysis, resulting six maps.

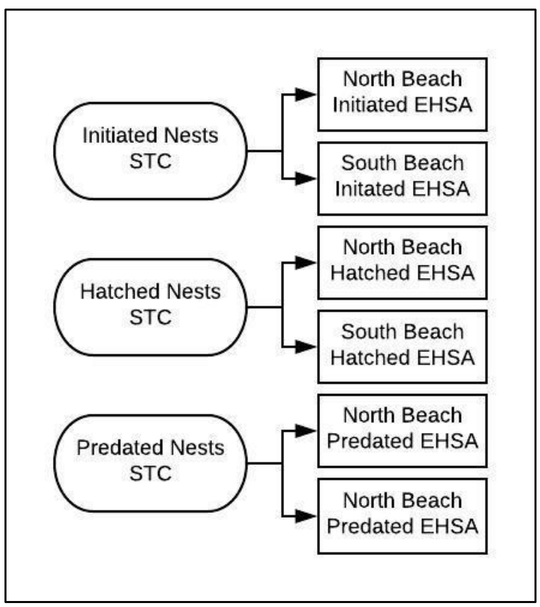

Figure 15. Workflow Diagram of EHSA

4.1.3 Space-time Cube 3D Visualization

After the EHSA, is run the results of the hot spot analysis are stored in the NetCDF cube and can be visualized in 3D using the Visualize Space Time Cube tool. There are several options for choosing a display theme; for this analysis, displaying the hot and cold spot results was used. This visualization helps to understand the structure of the STC and allows exploration of the results of the EHSA. This analysis used the 3D visualization to analyze different locations and years to understand locations that did not indicate hot spots using the ESHA and the ability to look at yearly trends. Thus, it is possible to explore each year in each location by moving through the bin stacks. Maps show a general view but mainly this tool supports managers to explore the data and investigate areas, such as sand sheets, where hot spots appear after years of no hot spots. Several maps were created to present the 3D stacks in each beach section; however, this tool is more useful as an interactive exploratory tool. Therefore, analysis occurred interactively in ArcGIS Pro and results are discussed and illustrated in Chapter 5.

4.2 Wrack and Nest Initiation Exploration

An initial exploration on wrack transect data was conducted to gain insight on how wrack abundance may impact nesting and help guide future work beyond this study. This initial analysis was designed to determine if more nest initiations or successful clutch hatches occur during periods of high wrack indices (abundance). The final 2002-2018 plover nest shapefile (excerpt in Appendix A) was used in Excel to conduct a simple pivot table sort. Nests were separated into two categories, all nests initiated and clutch hatch success, then sorted to determine the number of nests initiated and hatched during each wrack value (0-5). The results provide a quick look at which wrack category is more prevalent for 2012-2018 plover nest initiation and successful hatches.

Chapter 5 Results

The results from the HSA, the EHSA and the STC hot spot visualization provide useful information regarding the nesting trends of the plover and where key nesting hot spots are located at VAFB. First, the results of the annual HSA are presented. Then the results of the EHSA are reviewed followed by the STC hot spot visualization in 3D. The final section presents the results from the nesting wrack analysis.

5.1 Annual Hot Spot Analysis

While comparing the annual HSA results, it was difficult to distinguish variations between years given there were 102 maps to compare. It became clear that visualization of the STC hot spots through the EHSA allowed for easier temporal analysis of the data. However, the annual HSA is useful for looking at specific years in specific locations. In this section, the WAL and SNO restoration areas are highlighted for evidence of changes in nest initiation and hatched hot spots from 2003-2018, pre- and post-restoration. Restoration began in the winter of 2009 with completion in 2014/2015. Aerial imagery shown in all figures is from 2018 (post-restoration), therefore visual representation of actual topography of beach is incorrect when looking at past years data projections.

Figure 16 shows the raw nest point distribution pre- and post-restoration. Prior to restoration (2002-2008), nest distribution was exclusively found on the coastal area in front of the foredune, while post restoration (2009-2018), nest distribution spread to the east behind the foredunes.

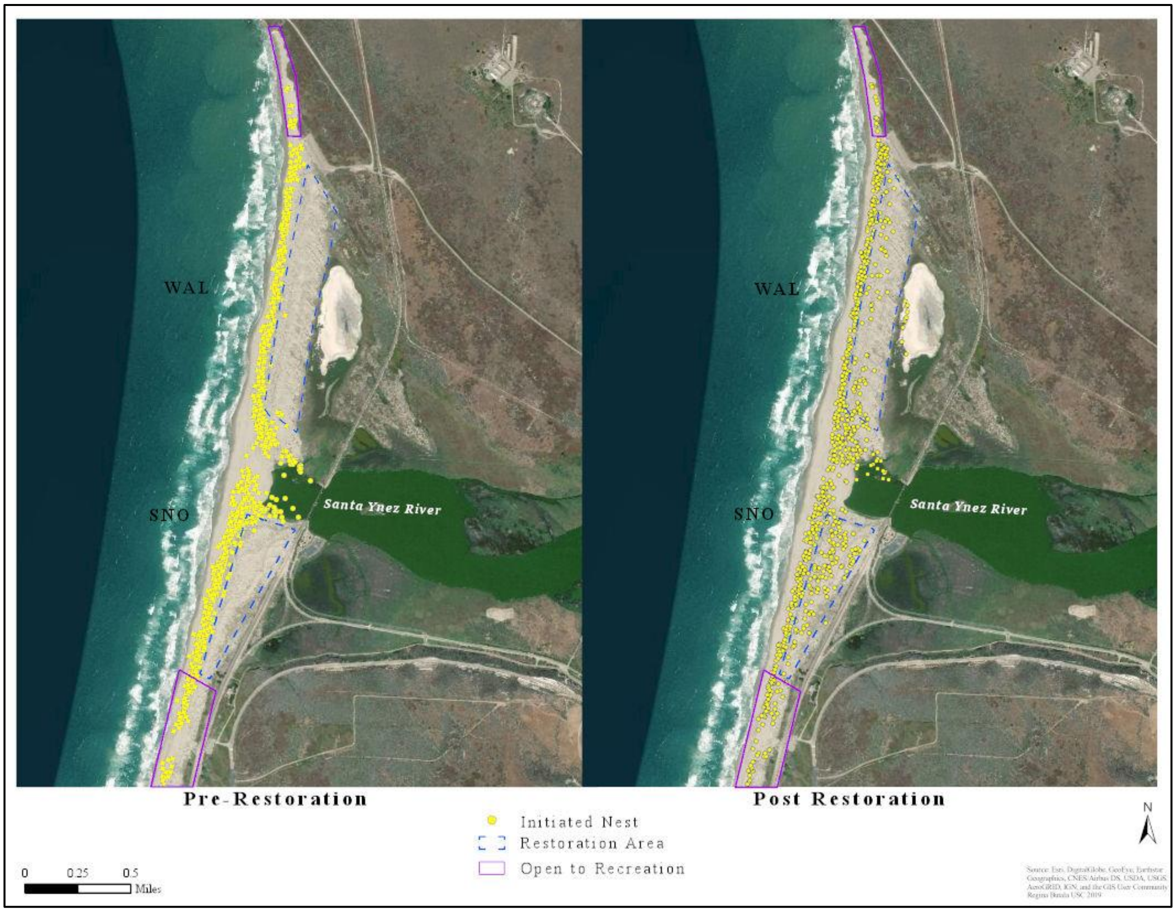

Figure 16. Restoration Area Initiated Nest Points. Pre-restoration (left), 2002-2008, nest points initiated showing nest distribution primarily on the coast and along the river mouth in WAL and SNO. Post-restoration (right), 2009-2018, nest points initiated showing nest distribution along the coast and further to the eastern boundary.

5.1.1 Initiated Hot Spot Distribution on WAL and SNO Restoration Areas

Figures 17 through 21 show the initiated nest hot spot distribution for WAL and SNO from 2002-2018. Initiated hot spot distribution on WAL remained consistent in most years pre- and post-restoration on the southern edge of the restoration area and sporadic on the beach front. The southern area is subjected to yearly influence of the Santa Ynez river mouth that may influence and cause fluctuation in habitat quality from year to year. This hot spot did not change significantly over the years after restoration, however, a new hot spot appeared at the north end after restoration efforts (Figure 21).

SNO restoration did not show any hots spots until post-restoration years, 2014, 2016, and 2017 (Figure 20 and 21). In 2004, a large cold spot was detected along the eastern edge of both restoration areas (Figure 17). Incidentally, this is where the thickest area of invasive vegetation (beachgrass and golden wattle) was present before its complete removal in 2009. No other cold spots were detected in all years.

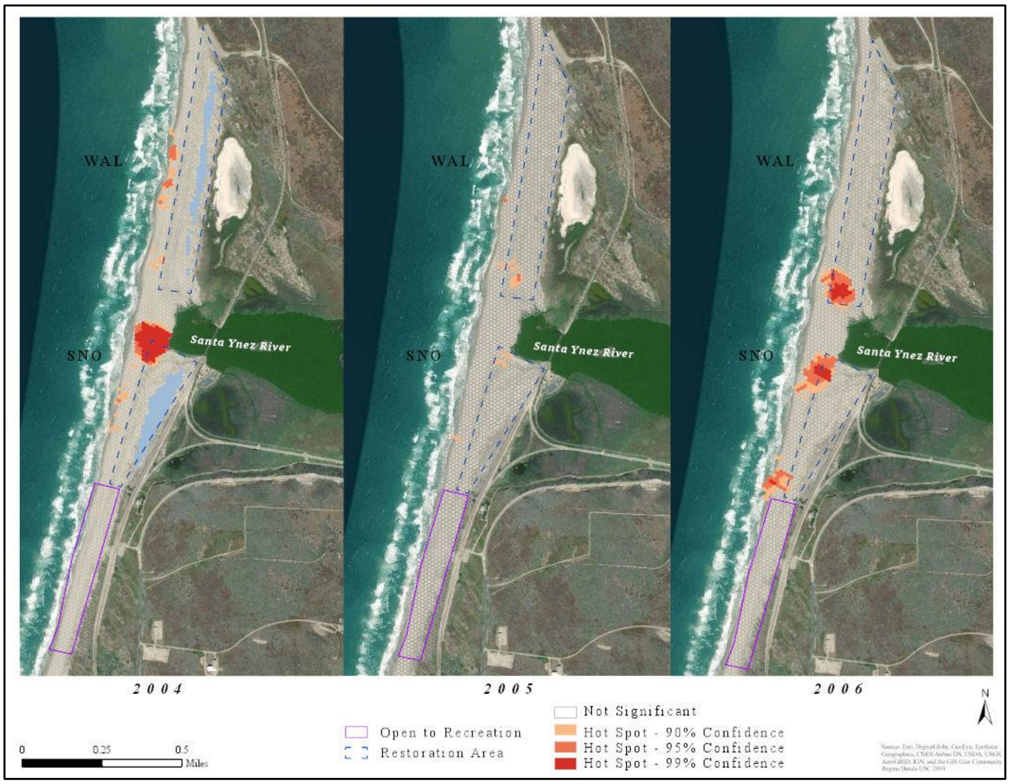

Figure 17. Restoration Areas Initiated Nest Hot Spot Analysis 2004-2006. This figure shows three years of nest initiation hot spots in the WAL and SNO restoration areas.

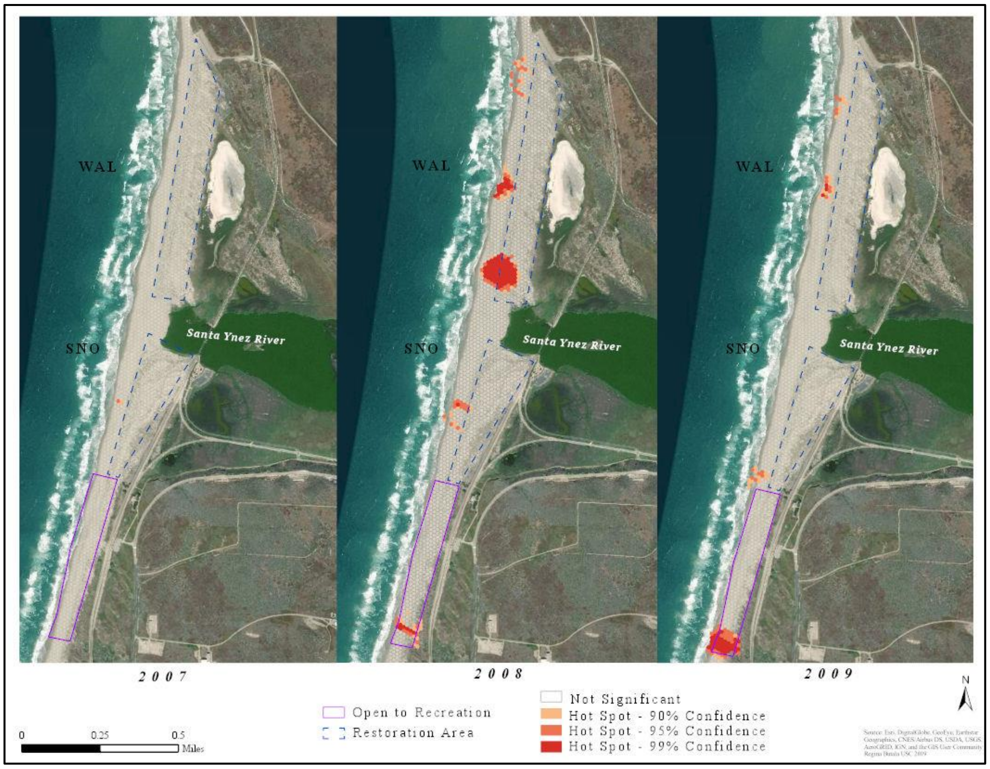

Figure 18. Restoration Areas Initiated Nest Hot Spot Analysis 2007-2009.

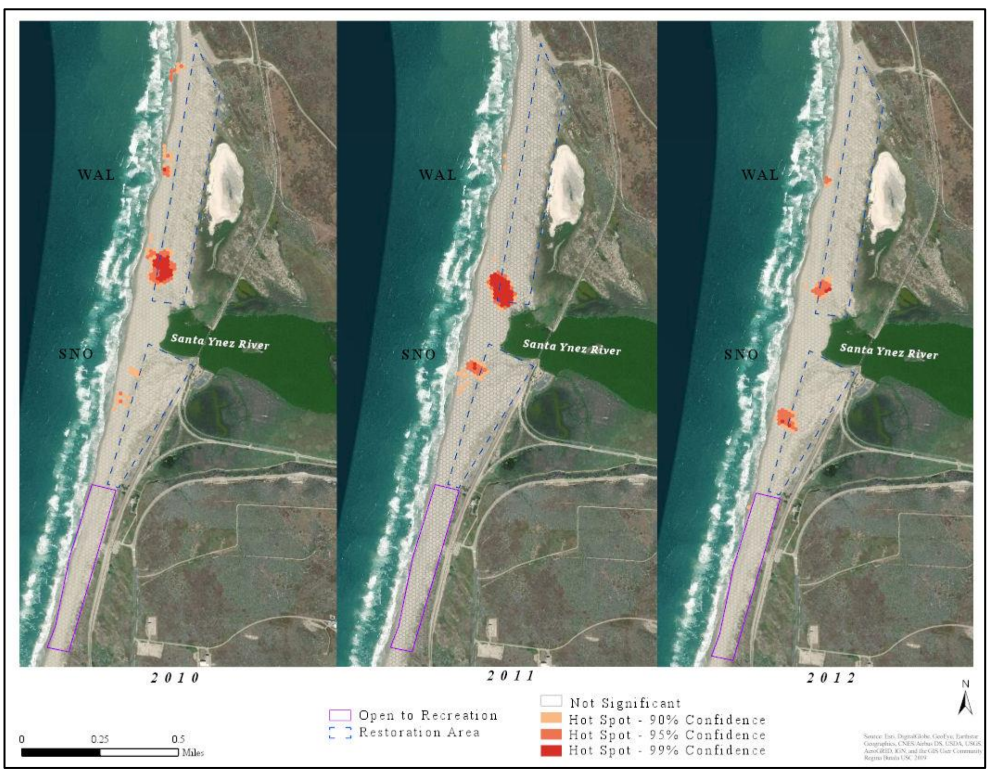

Figure 19. Restoration Areas Initiated Nest Hot Spot Analysis 2010-2012.

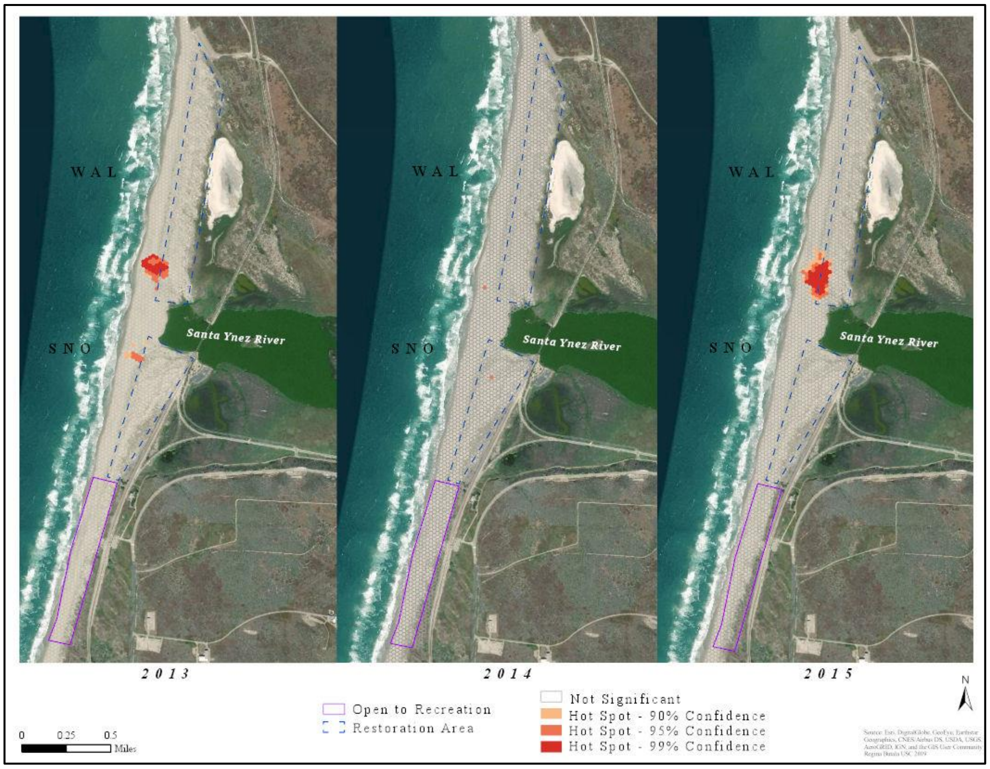

Figure 20. Restoration Areas Initiated Nest Hot Spot Analysis 2013-2015.

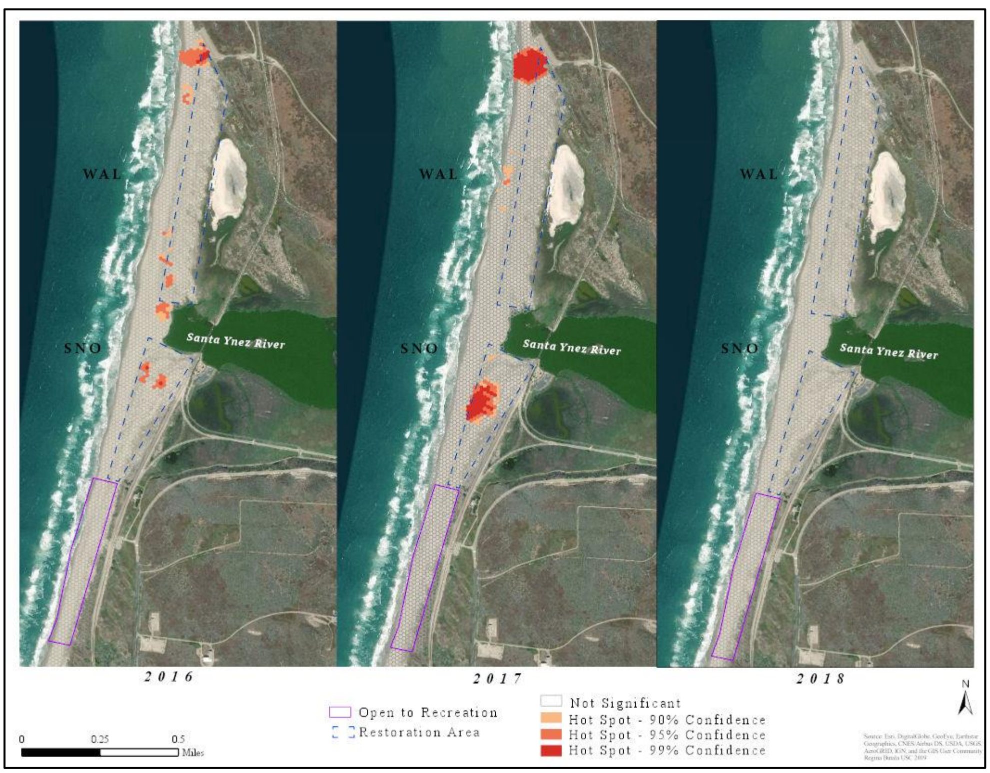

Figure 21. Restoration Areas Initiated Nest Hot Spot Analysis 2016-2018.

5.1.2 Hatched Hot Spot Distribution on WAL and SNO Restoration Areas

Hatched hot spot distribution followed a similar pattern as the initiation hot spots. At SNO for all years prior to restoration, there were no hot spots detected except for northern and coastal areas. The northern part of the restoration area, like WAL southern area, is impacted by the Santa Ynez river with year to year habitat quality fluctuation likely impacting nesting. In 2014, the largest hot spot occurred in the center of the restoration area. Followed by 2016-2017 hot spots in that same area. Figures for hatched HSA for WAL and SNO restoration areas are in Appendix C.

5.2 Emerging Hot Spot Analysis

Space-time emerging hot spot analysis was run on three categories of plover nest data: all initiated nests, successful clutch hatches, and predated nests. Only statistically significant hot spot and non-significant trends were found on the beach segments; no statistically significant cold spots were detected. Hot spot patterns were more prevalent on the southern region of North beach and on the northern region of South beach, both nearby river systems. Across all three categories, the analysis identified only seven hot spot pattern categories: no pattern detected, historical, new, consecutive, intensifying, persistent, and sporadic hot spots. Definitions of these seven hot spot patterns are shown in Table 11 (See Appendix B for all hot spot category definitions).

Table 11. Seven hot spot categories detected

Pattern Name	Definition
No Pattern Detected	There were not hot or cold spot patterns found in area
New Hot Spot	A location that has never been a hot spot before but is a hot spot for the final time step
Consecutive Hot Spot	A location with an uninterrupted run of hot spot bins in the final time-step intervals. Less than 90 percent of all bins are hot spots and the location has never been a hot spot prior to the final run.
Intensifying Hot Spot	A location that has been a hot spot for 90 percent of the time-step intervals including the final interval. The intensity of clustering of high counts in each time step is increasing overall and the increase is statistically significant.
Persistent Hot Spot	A location that has been a hot spot for 90 percent of the time-step intervals with no apparent trend indicating an increase or decrease in the intensity of clustering over time.
Sporadic Hot Spot	Areas that are hots spots at one time-step interval then not a hot spot. Less than 90 percent of the time-step intervals have been hot spots and never have they been cold spots.
Historical Hot Spot	At least ninety percent of the time-step intervals have been hot spots, but the most recent time period is not hot.

5.2.1 North Beaches

Most of the North beach area did not show statistically significant trends. The ESHA detected seven hot spot pattern categories, there were no statistically significant cold spots found on any of the beach segments. Most hot spot categories occurred on SAN segment around San Antonio river mouth. There were hot spots detected in each nest category in all beach segments except for MIN (Table 12). There is no figure representing MIN beach segment due to no results found.

Table 12. North Beach Hot Spot Categories

	New	Historical	Consecutive	Intensifying	Persistent	Sporadic
Initiated						
SAN	7	-	17	5	25	117
SHN	-	-	-	-	-	5
SHS	2	-	1	1	-	47
Hatched						
SAN	5	1	-	-	4	72
SHN	-	-	-	-	-	1
SHS	-	-	-	-	-	17
Predated						
SAN	7	-	10	-	-	93
SHN	-	-	-	-	-	8
SHS	1	-	2	-	-	21

The spatial distribution of North beach hot spots is shown in Figure 22 through 24 for SHN, SHS, and SAN. SHN had the least number of hot spots detected, with only a few sporadic hot spots in all three nesting categories which occur on the southern section. SHS resulted in a new hot spot for both nest initiations and predations in the mid to southern section. Sporadic hot spots occur on the extreme south end of SHS for both hatched and predated nests, where in the initiated nest results, they occur throughout. There was one consecutive hot spot in the same transect block area as the new hot spots in the initiated nest category at SHS. SAN segment EHSA resulted in more hot spots than SHN or SHS, as shown in Figure 24. Consecutive hot spots occur on SAN throughout the segment with one detected on the far east of the southern sand sheet. Most of the significant hot spots occur north and south of the San Antonio river mouth and sandspit.

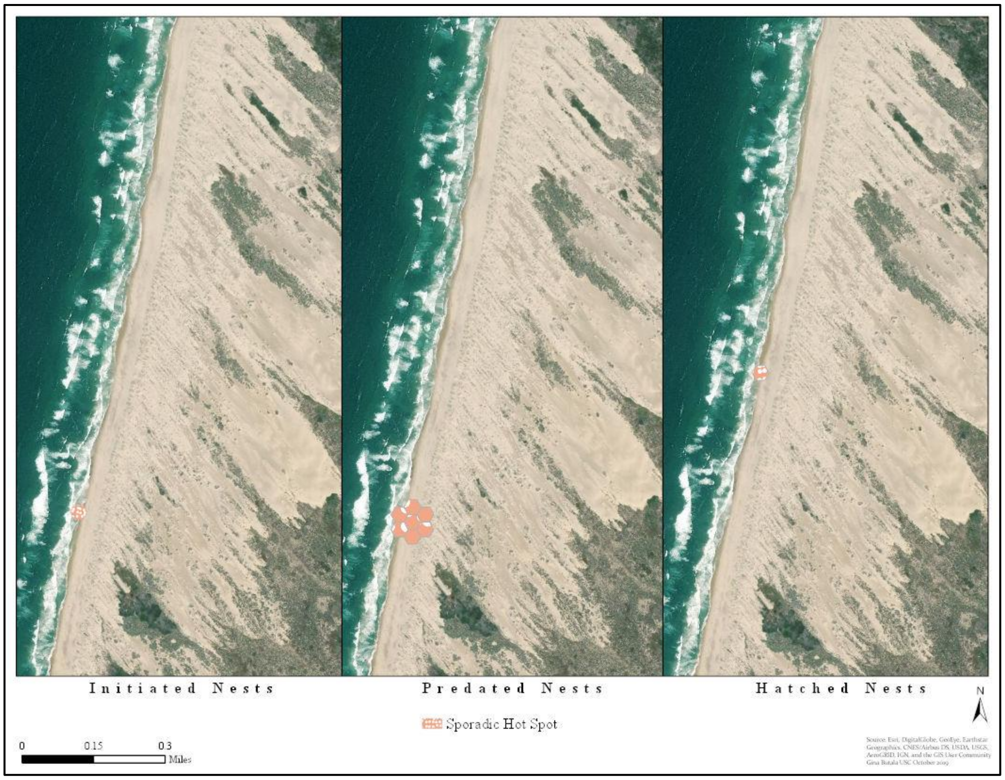

Figure 22. SHN – EHSA Results

Figure 23. SHS - EHSA Results

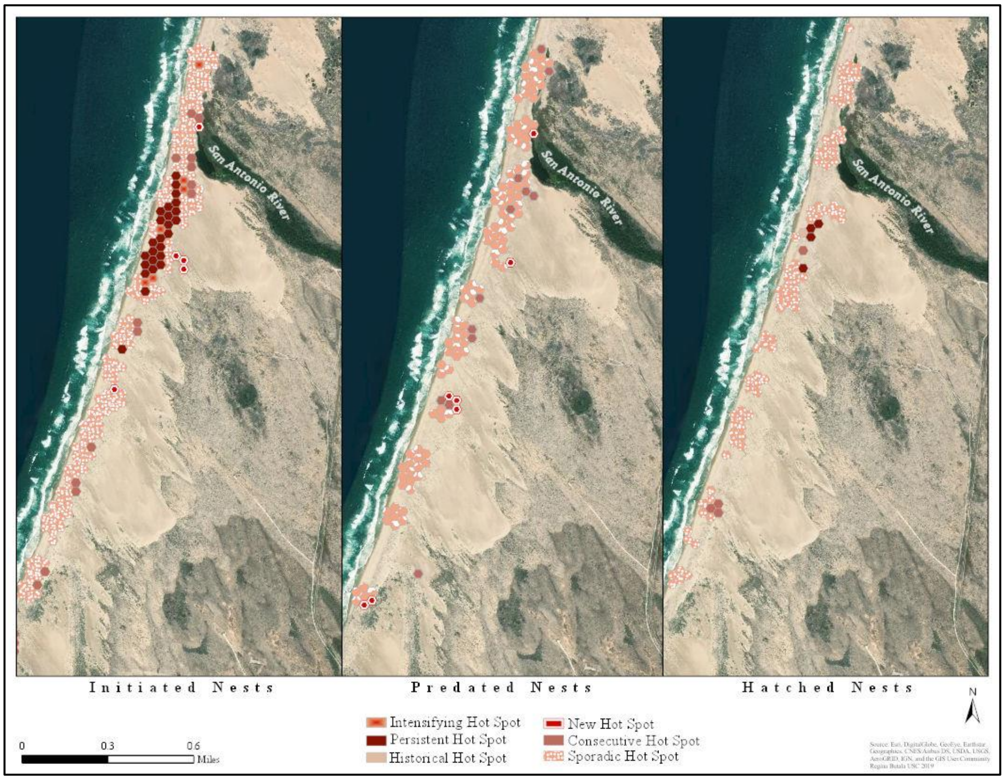

Figure 24. SAN - EHSA Results

5.2.2 South Beaches

The EHSA detected three hot spot pattern categories on South beach; there were no statistically significant cold spots (Table 8). The spatial distribution of hot spots on South beach are shown in Figures 25 through 27 for WAL, SNO, and SSO. All beach segments contain hot spot areas; however, the areas open during the nesting season to public recreation on WAL and SNO had no hot spots (recreation areas are shown on Figures 25 and 26 with a purple boundary). A high number of hot spots occurred within the vicinity of the Santa Ynez River mouth on the southern end of WAL and northern end of SNO in all nesting categories. There are no hot spots along the eastern edge of the beach segment. SSO hot spots occur to the south of Bear Creek in every category along “border trail”.

Table 8. South Beach Hot Spot Categories

	New	Consecutive	Sporadic
Initiated			
WAL	4	17	18
SNO	7	15	38
SSO	-	1	1
Hatched			
WAL	1	4	17
SNO	1	13	16
SSO	-	-	1
Predated			
WAL	4	9	6
SNO	9	12	24
SSO	-	1	6

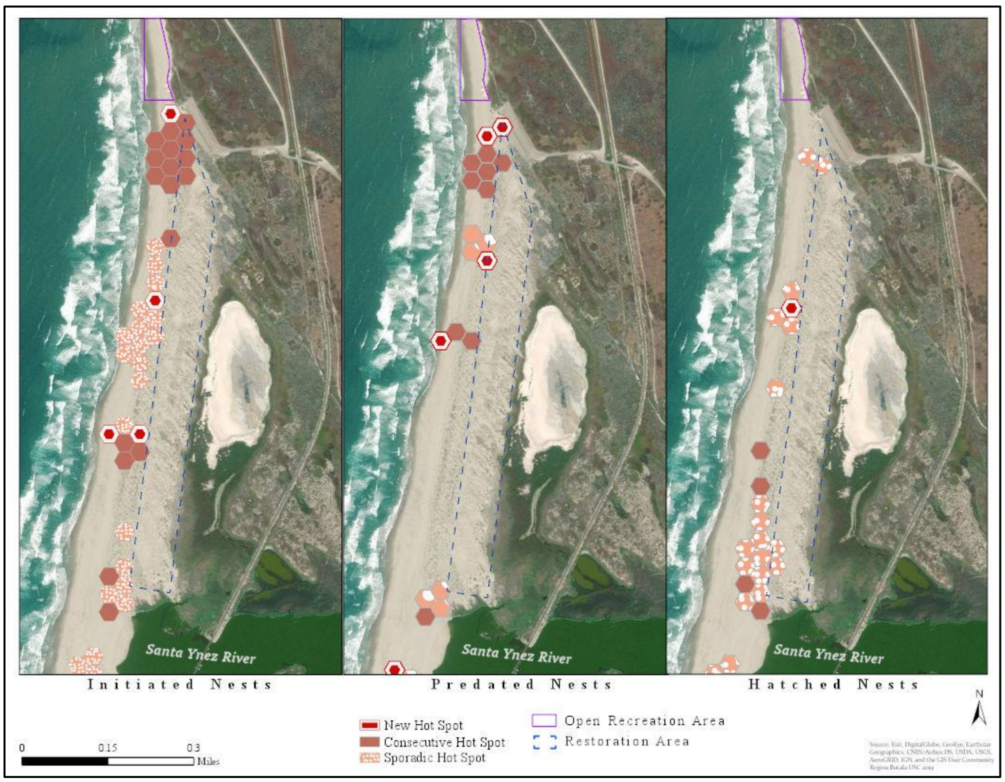

Figure 25. WAL - EHSA Results

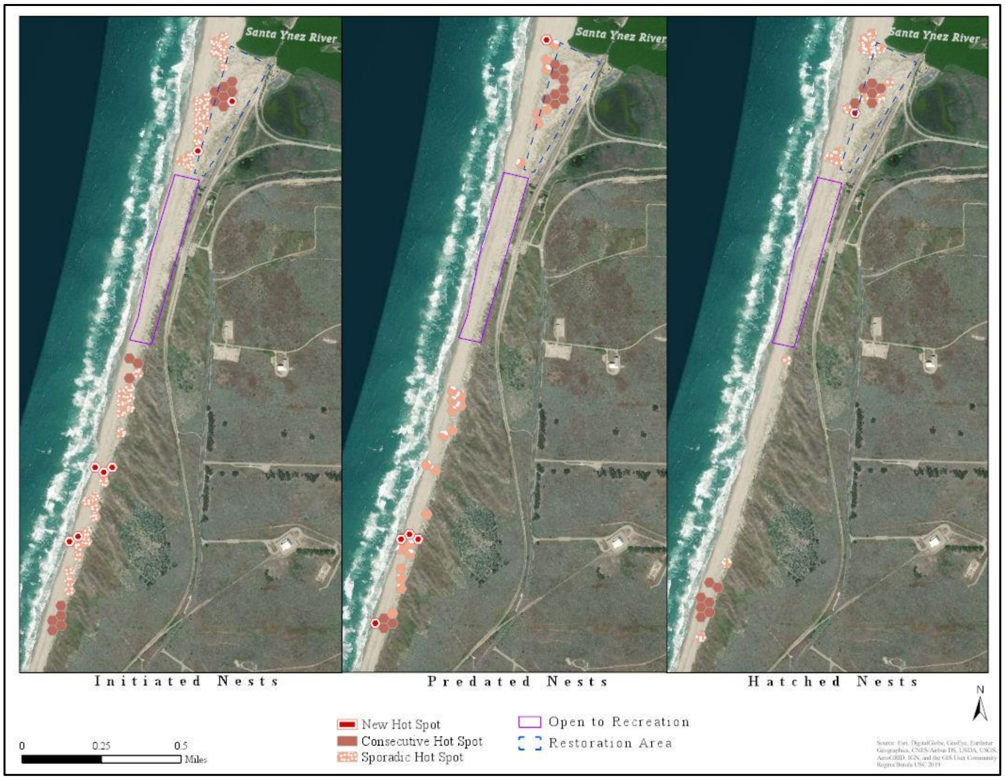

Figure 26. SNO – ESHA Results

Figure 27. SSO - ESHA Results

The distribution of hots spots on WAL varied in all three nesting categories. Initiated nests hot spots occur throughout WAL with many hexagons at the north end. Predated nesting hot spots occur primarily on northern end of the segment, while hatched nests to the southern end. SNO initiated and predated nesting hot spots have a similar spatial distribution. However, hatched nest hot spots occur primarily on the northern and extreme southern end of the segment.

SSO had very few hots spots detected in only two hot spot categories. In each nesting category there is a consistent hot spot in the vicinity of Bear Creek. Nest initiation has a consecutive hot spot at the northern end while predated nest hot spots occur in two area above Bear Creek.

5.3 Space-time Cube Hot Spot 3D Visualization

Visualizing the STC hot spot pattern showed only hot spots or non-statistically significant trends in all beach segments. Figures 28 through 36 show each section for initiated nests while predated and hatch nest categories are in Appendix D. On these figures, each bin column contains 17 time-steps that represent each year of plover nests since 2002 with the most recent year, 2018, at the top of the stack. Most stacks that were not statistically significant were spatially distributed to the eastern edge of the habitat in all sections. The stacks that have no hot spots remained consistent through all years. Those with hot spots remained in consistent areas but varied in significance throughout the years.

MIN beach section did not show any hot spots in the ESHA, however, when looking at all years in the STC visualization, the temporal distribution of hot spots can be observed. MIN did not show any hot spots since 2014 but prior to that hot spots are shown predominately on the northern end. Between 2009-2013 hot spots are seen on the sand sheets of northern MIN.

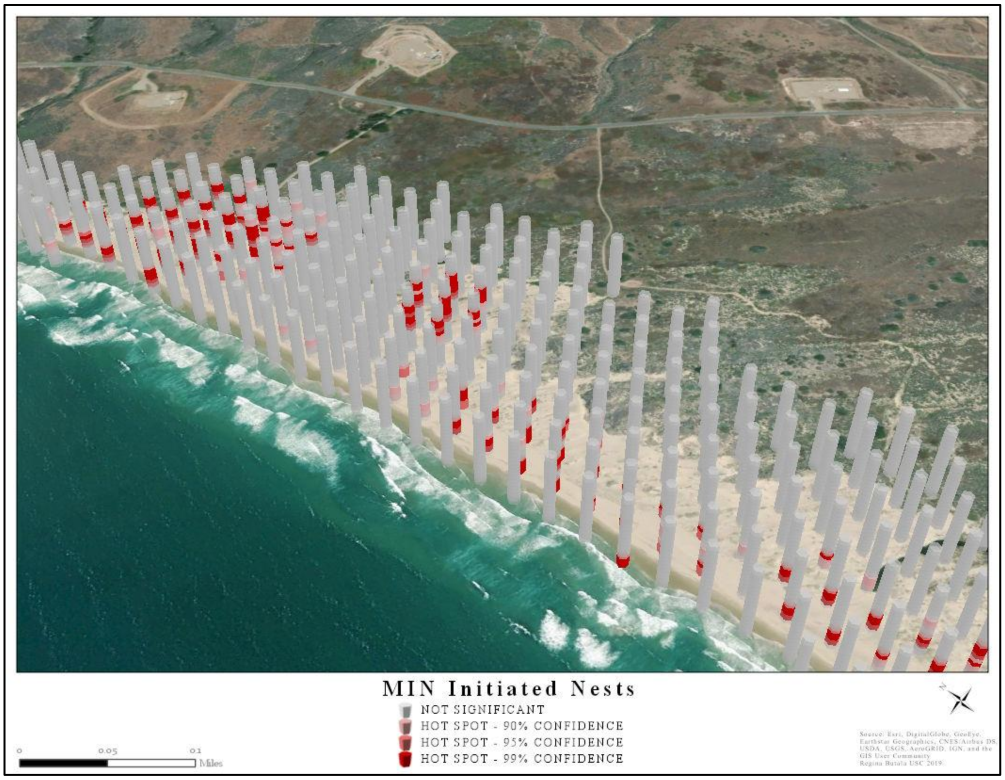

Figure 28. MIN - STC Initiated Nest Hot Spot Visualization.

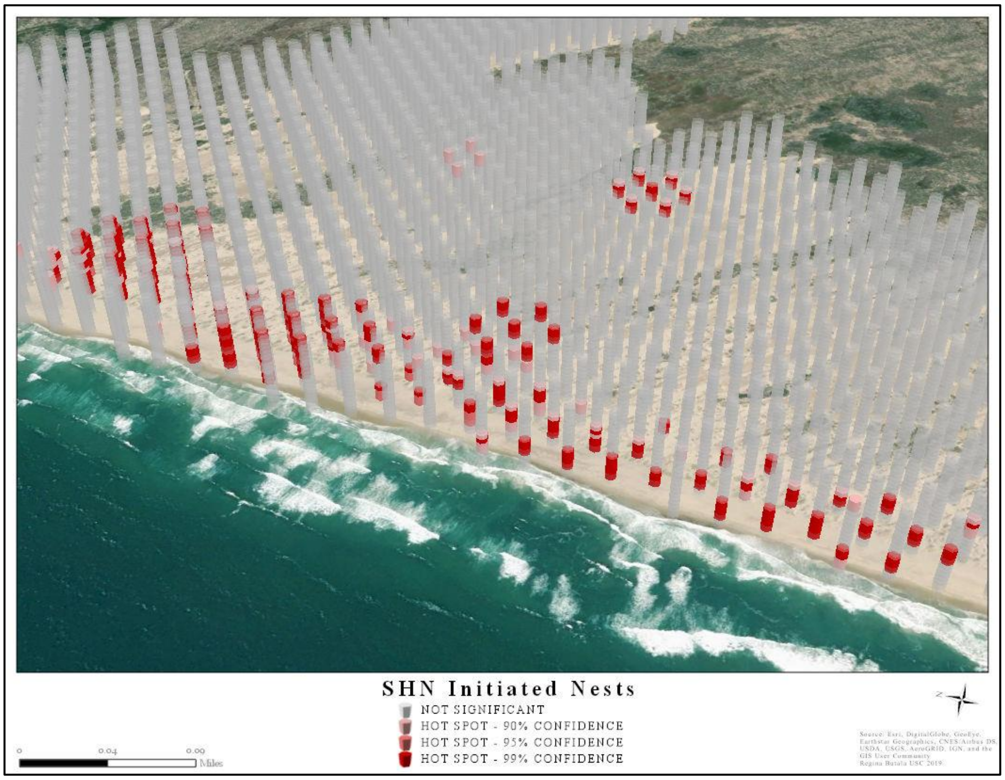

Figure 29. SHN – STC Initiated Nest Hot Spot Visualization.

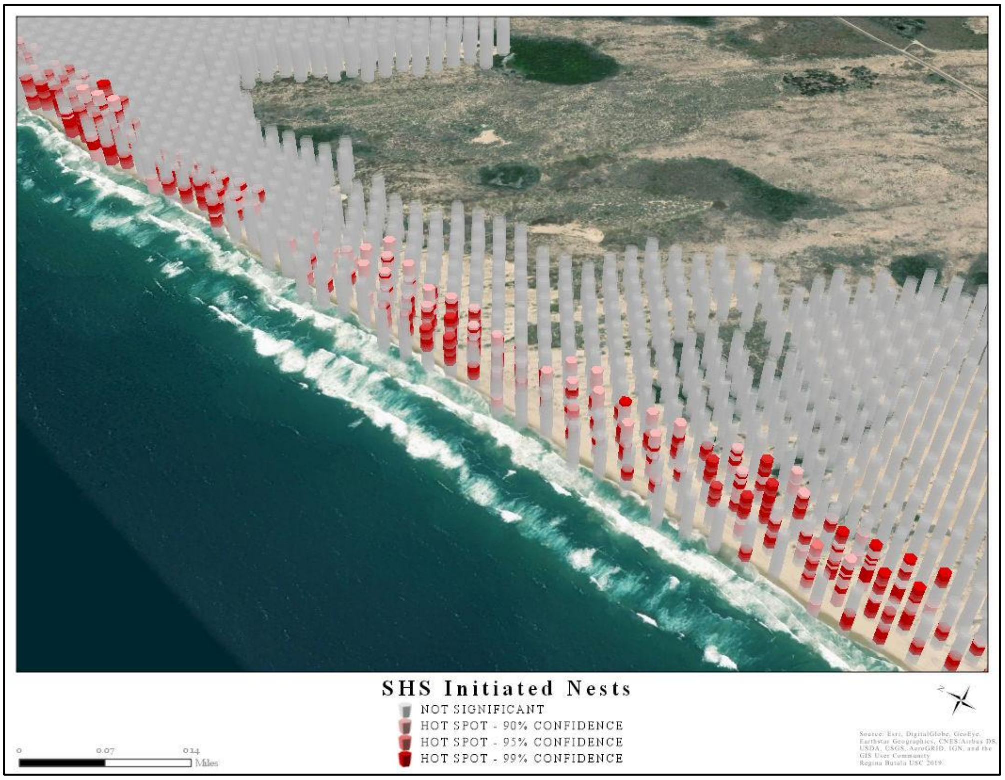

Figure 30. SHS – STC Initiated Nest Hot Spot Visualization.

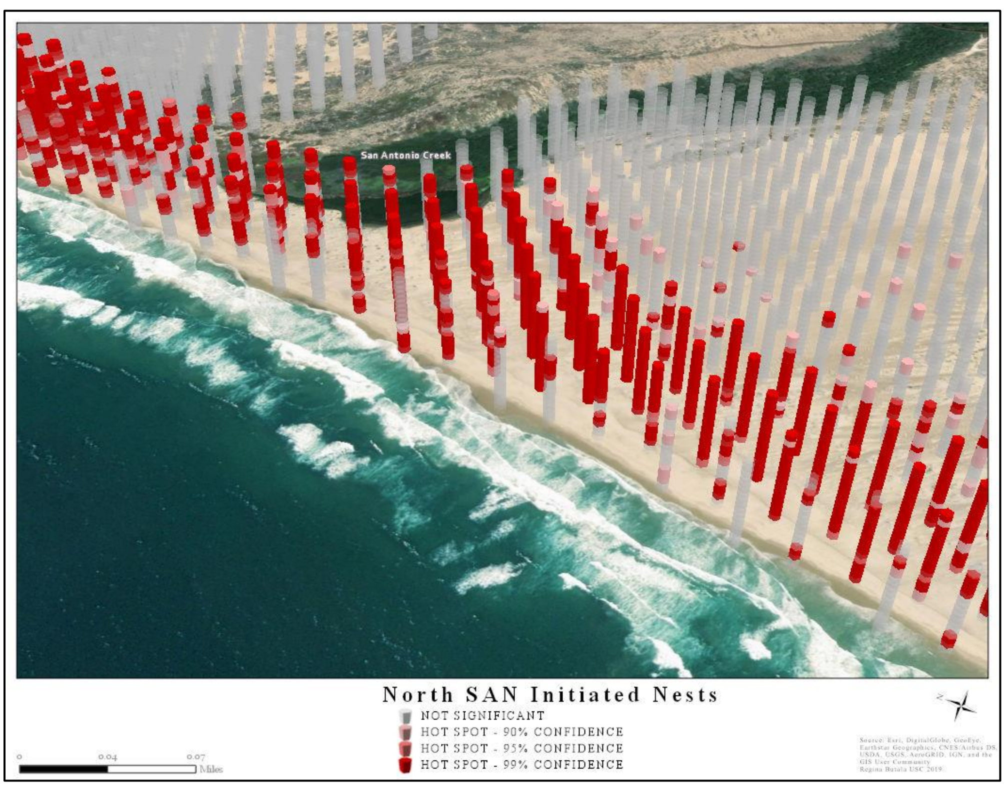

Figure 31. North SAN – STC Initiated Nest Hot Spot Visualization.

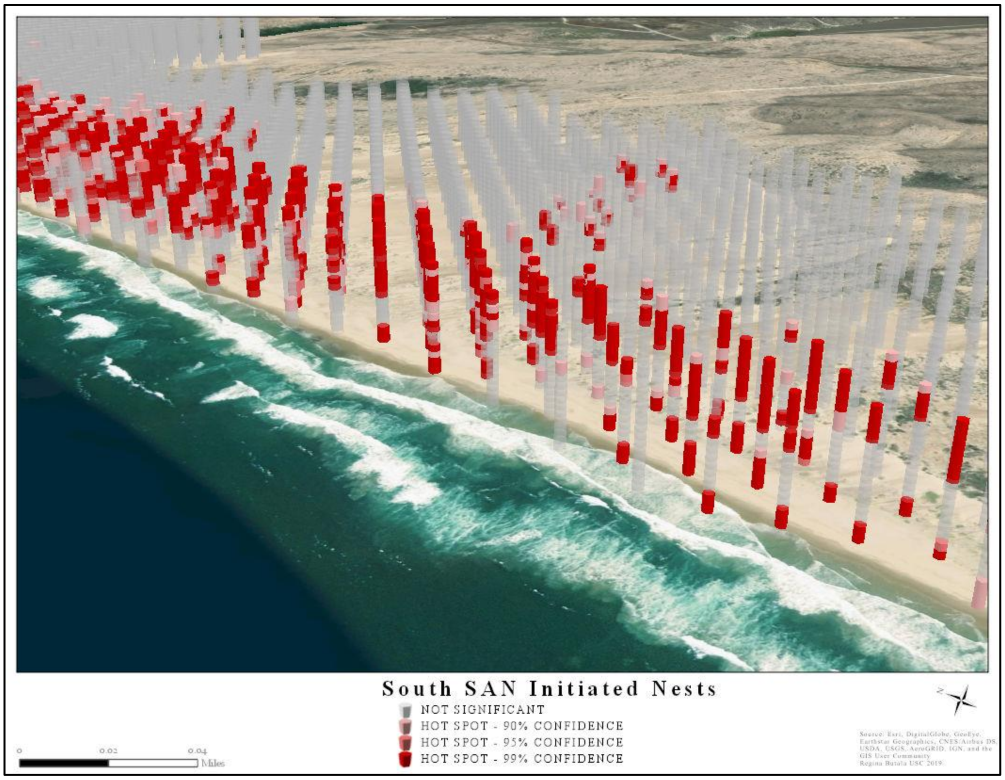

Figure 32. South SAN – STC Initiated Nest Hot Spot Visualization.

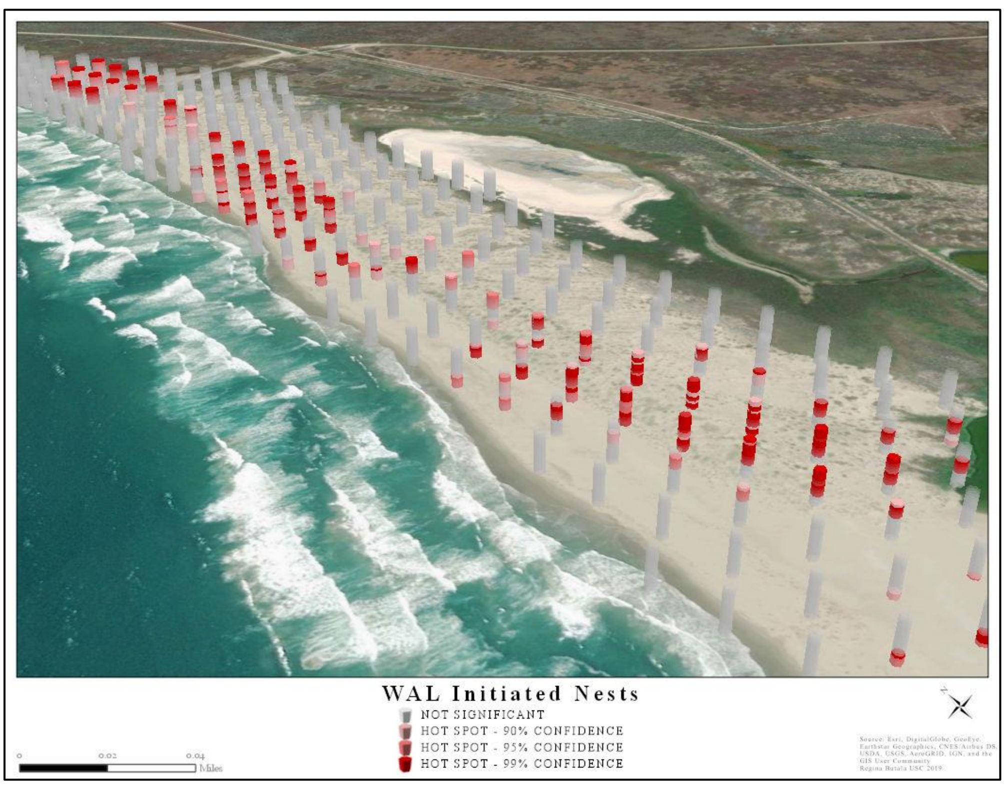

Figure 33. WAL – STC Initiated Nest Hot Spot Visualization.

Figure 34. North SNO – STC Initiated Nest Hot Spot Visualization.

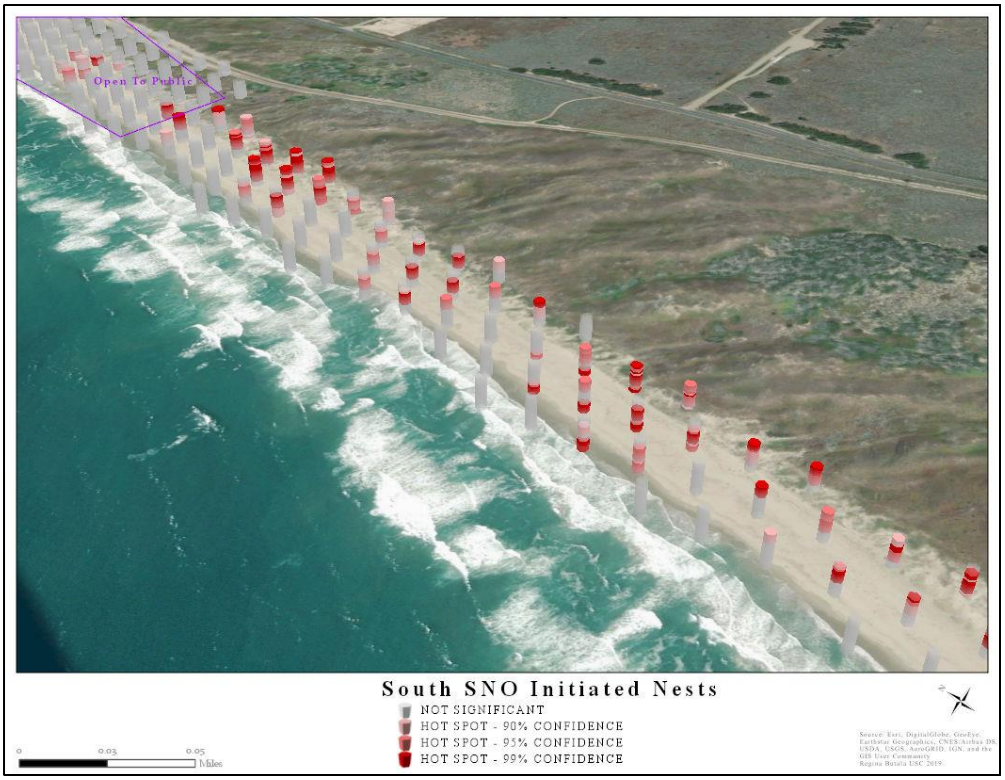

Figure 35. South SNO – STC Initiated Nest Hot Spot Visualization.

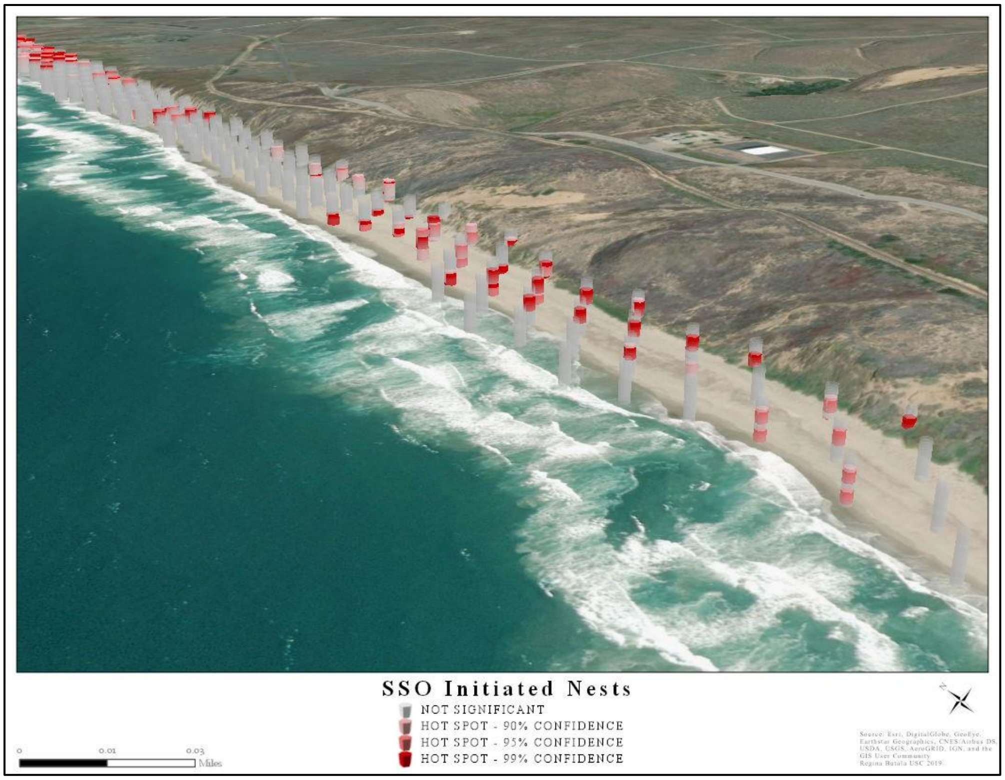

Figure 36. SSO – STC Initiated Nest Hot Spot Visualization.

SHN and SHS hot spots occur mainly on the beach front and foredune area earlier in the time series except for central SHN sand sheet showing hot spots prior to 2013. Early in the time series SHS had more hot spots at the northern end while later in the time series the southern end showed an increase in hot spots.

SAN beach section contains the most bins containing hot spots within all stacks when compared to all other beach sections (Figure 31 and 32). This supports the findings in the EHSA showing SAN with most of the hot spots and in all categories. Hot spot distribution in the sand sheets at south SAN end in 2013, like those on MIN and SHN. This suggests some anomaly, when compared to all years, in 2013 that caused a shift in the hot spot distribution on north beach further east on all segments.

On South beach, hot spots remain relatively consistent throughout, those stacks with no hot spots remain that way through the all years while others show fluctuations. WAL hot spot distribution remained on the southern end in most years but more recently heavily distributed on the central and the northern areas, otherwise sporadic throughout. On SNO, hot spots were distributed mainly at the northern end. In the EHSA, SNO open to recreation does not show any hot spot categories. However, like MIN, the STC shows a few hot spots in early years, especially at the south end (Figure 34 and 35). SSO also showed limited hot spots in the EHSA and in the STC, most of the hot spots occur in recent years.

Hatched and predated STC visualizations show similar distributions, with several years that appear to change distribution (Appendix D). Such as in 2010 and 2013 many predated hot spots appear along SNO segment. Hatch hot spots on South beach seem to follow a similar overall distribution as initiations.

5.4 Wrack Abundance

A total of 1713 nests were initiated between 2012-2018 on North and South beach of VAFB. As described above, during these years, wrack accumulation was assessed weekly with an abundance value given to each surveyed transect. During the data manipulation stage of this research, each nest was assigned the wrack index value collected for the relevant transect during the week when the nest was first established. All nests between 2012-2018 were included in this analysis. This part of the analysis was designed to determine which wrack index value had the highest percentage of initiated nests regardless of fate and of all successful hatched nests to see if high wrack values correlate with higher percent of initiated nests or successfully hatched nests. Surprisingly, a similar trend was found for North and South beach with a higher percentage of nests in both categories having a low wrack index value of 1. Figure 37 summarizes these results which are discussed in the following sections.

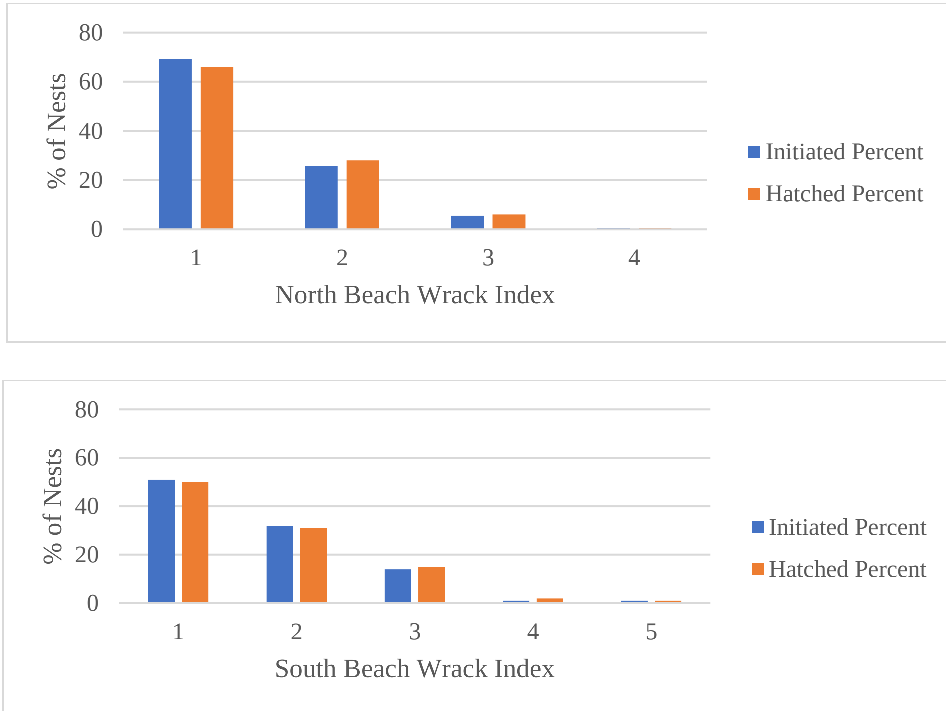

Figure 37. North and South Beach wrack values indicating the percent of initiated and percent hatched nests per wrack index value for 2012-2018.

5.4.1 Initiated Nests Wrack Values

Approximately 50 percent of all South and 70 percent of all North beach nests were initiated during weeks of level 1 wrack (low abundance). Level 2 wrack nests accounted for 30 percent all South and 26 percent all North nests respectively. Finally, level 3 and above wrack nests accounted for 15 percent South and 7 percent North. There were very few initiated nests during weeks of level 4 wrack values and none in level 5.

5.4.2 Hatched Nests Wrack Values

Successful clutch hatches made up 45 percent of all initiated nests (779) between 2012-2018. Out of these nests 65 percent on North and 45 percent of South beach hatched nests occurred during wrack index values at level 1. Approximately 30 percent of both North and South successful hatched nests had level 2 wrack index with 6 percent of North and 15 percent of

South in level 3. Less than 5 percent of hatched nests on both beach sections had level 4 wrack value with only 1 percent of hatched nest occurring in level 5 at South beach.

Chapter 6 Discussion and Conclusions

The plover population at VAFB has been monitored since it was listed as threatened by the USFWS in 1992. However, only in the last 17 years have consistent data regarding nest success, population fluctuation, and habitat been collected (Robinette et al. 2018; Mantech 2010). Throughout the literature, habitat restoration and predator management have been identified as the most prominent management strategy within the plover breeding range (USFWS 2007), each site manger varying in approach and methodology. At VAFB, predator management successfully occurs on the fly, without prior knowledge of possible predator hot spot trends. Understanding where predator hot spots are will provide managers with preemptive primary focal areas. Large scale restoration has been conducted with little prior research to guide project scope and locations, often going about it in "good faith" that the plovers will use the area if invasive vegetation is removed or if dunes are reconstructed. As a result, little is known about the impact of restoration or whether these locations serve as hot spots for nesting plovers.

To understand the relationship between the distribution of nesting hot spots, predation, and restoration 17 years of nesting data were used to assess spatial and temporal nesting. This research addressed the following questions:

1) Are there consistent temporal and spatial nesting hot spots in three categories: nest initiation, successful clutch hatch and clutch failure due to predation, and if so, what are the key areas for focusing future predator management and restoration work?
2) Do recent habitat restoration sites have hot spots of plover nesting pre-restoration Have hot spot distributions changed post restoration in these areas?
3) Is there a correlation between high wrack abundance and nest initiation or hatch?

6.1 Result Overview

The data used in this study underwent an extensive overhaul in formatting and cleansing. As a result, a streamlined file was created for use in the analyses and a conceptual model of a relational database was structured for future studies. Three different forms of analysis were conducted to determine the spatial distribution of nesting hot spots. Overall this study found that hots spots do persist in certain areas of VAFB beaches annually and hot spot analysis can be used as an effective tool in analyzing nesting patterns. Even though the annual hot spot analysis did not provide useable results on the study site scale, it proved to be an excellent method to assess restored beach areas pre- and post-restoration. STC and ESHA tools effectively captured the spatial and temporal distribution of nesting at VAFB at the study site scale, providing answers to the research questions in this thesis.

6.1.1 Are there consistent temporal and spatial nesting hot spots in three categories: nest initiation, successful clutch hatch and clutch failure due to predation? What are the key areas for focusing future predator management and restoration work?

While considering hot spots of nesting, the EHSA is the best tool to look at an overall temporal view of the spatial nesting patterns. In this analysis, hot spot categories given more consideration are those that are consecutive, persistent, and intensifying. In this discussion, these categories are called significant hot spots. Hot spots classified as sporadic or new are not considered significant for the purpose of this thesis since they occur in less than 90 percent of the bins in a stack or, in the case of a new hot spot, never until the most recent year. The new hot spot category could serve as an alert system if this analysis is run with each new year of data, but here they are not considered for recommendation for restoration or predator activities for broadscale management.

On North beach, the segment with the most significant hot spots in all nesting categories is SAN followed by SHS (which is on the northern boundary of SAN). The most significant hatch hot spots occur at the northernmost end surrounding the San Antonio River mouth. Predated and initiated hot spots are scattered throughout SAN, however, significant predated hot spots occur on the coastal areas throughout the northern half of the segment. Initiated nests share a similar pattern as predated, however just south of the San Antonio river mouth, there is a large hot spot.

A similar pattern is found on South beach, with the most significant hot spots occurring north and south of the Santa Ynez River mouth. Both initiated and predated nest hot spots share a similar pattern throughout, however most notably at the northern end near the area open for public recreation.

This distribution supports the hypothesis that most initiated and hatched hot spots will occur surrounding the river mouths. On South beach, predated hot spots on SNO appear to concentrate near the areas open to recreation as well as the river mouths. This is possibly due to the increase in human related activities, such as trash, drawing nest predators to the area. Areas around the river mouths should continue to be areas of restoration consideration to improve habitat quality. Predator management efforts should be focused along the river mouths as well as areas adjacent to the public areas at WAL and SNO.

6.1.2 Which beaches of VAFB have hot spots of plover nesting and do these areas correlate with recent habitat restoration activities? Have hot spot distributions changed post restoration in these areas?

There are two management implications that result from locating hot spots of nest initiation and nest hatching at VAFB. The first is that future restoration efforts can be focused in hot spot areas with the assumption that habitat enhancement will improve and provide better habitat quality. The second is to assess past restoration efforts to determine if these efforts took place in a hot spot area. MIN and SHN beach segments have had relatively no hot spots in five years according to exploring the STC visualization and overall no significant hot spots were found in the EHSA; and yet restoration has ensued in this area within the last four years. Although the effects of this restoration on the plover breeding population at VAFB may have yet to be expressed, no significant increase in nesting has occurred there in the last 4 years since restoration (Robinette et al. 2018). Nelson (2007) points out that without plover social cues or high numbers of actively nesting plovers in the area, restoration in areas where there are no hot spots of activity may fail to bring an increase in prospective breeders. Therefore, the results of "good faith" restoration may prove difficult in increasing nesting (Ahlering and Faaborg 2006). Exploring the possible reasons MIN through SHS lack high number of breeding plovers compared to other beaches (in spite of its available habitat) would be important in attempting to explain the southern population shift at North beach.

Northern SNO and all of WAL beach also underwent a large restoration, however this area had a significant amount of hot spot locations near the restoration area prior to restoration. Similar to Zarnestke (2010) findings in the Pacific Northwest Coast, at VAFB there was first a substantial increase in nesting in the two years following dune contouring followed by a drop off in nesting activity as the dunes began to fill in with native vegetation and dune slopes began to be reshaped naturally by beach processes. At SNO, new hot spots of nesting and hatching have been relatively consistent post-restoration (2014-2017), however, in 2018 no hot spots were observed. Tracking this pattern into the future will determine if restoration efforts will follow a similar declining fate without follow-up dune contouring (Zarnestke 2010). WAL beach had nesting and hatched hot spots prior to restoration in that area and although the distribution did not change significantly after restoration, hot spots size did increase during years that hot spots were present on the edges of the restoration boundary.

While comparing hot spots pre- and post-restoration does not give an overall analysis on plover productivity, it is a good indicator of important areas of nesting that are statistically significant. Powell and Collier (2000) recommend yearly evaluation of these restored nesting areas. This evaluation should not be based on the presence of nesting alone but tracking the productivity. Therefore, management should continue to track the response to restoration by the plovers annually. HSA is a powerful tool to detect changes in hot spot distribution and offers insight on the important nesting areas.

6.1.3 Is there a correlation between high wrack abundance and nest initiation or hatch?

This section of the research was an exploratory study. It is possible that food availability is not linked to nest site location because adult plovers are able to move up and down beaches for feeding. However, Colwell (2007) found that plover chicks less than three days old have significantly higher mortality rates than older chicks. When chicks hatch, they need to feed and traveling long distances for food or when energy intake is low, can cause slow growth in chicks which can increase mortality. In addition, traveling in search of food combined with low wrack abundance keeps chicks exposed for longer periods of time to predation risks. Exploring chick survival and food resources at VAFB would be a worthwhile research endeavor.

Though the results to this simple wrack exploration did not support the original hypothesis, that more nests would be established in areas with higher wrack abundance, this is a good step towards looking at how ocean subsidies may influence nesting. Many papers describe the correlation between high shorebird food abundance and high wrack deposits on beaches in the wintering season (Dugan 2003; Lafferty 2006), however, there is no literature regarding food abundance during the breeding season of plovers. While this thesis focused on restoration and predator management, other factors such as food availability may have a great impact on nest distribution at VAFB and should be explored.

6.2 Management Recommendations and Future Work

This study of spatial and temporal distributions of nesting hot spots and the relationship with management activities can be explored further in many ways. This thesis built a framework in which more questions can be studied, and additional exploration of the data can be initiated. Continuing yearly analysis of each breeding season will be valuable in understanding nesting trends in the future. While, plovers are one of the important threatened species on VAFB, applying this method of analysis to other species that share the beach ecosystem with the plover would help when applying management activities such as restoration to improve habitat for multiple species and understanding the impact of contouring or herbicide to non-target species.

This analysis lumped all predated nests into one category that included both coyote and raven predation. Predator control strategies varies significantly due to the terrestrial versus aerial nature of these two species. Nest predation hot spots should be evaluated in the future with these two categories to determine hot spots for each species and if there are any differences in where these two predators are taking nests. In addition, future EHSA should consider updating the polygon mask used in the parameter settings. Most of the stacks in the STC had no data resulting in no significant ranking in all HSA hexagons. This may impact the neighborhood statistical analysis in these tools. Consideration should also be given to reducing the amount of years used in the EHSA to determine if trends change using only most recent years. The tool requires at least six time-steps or six years of plover nesting data.

The focus in this study was on nesting distribution, however, the success of plovers is not merely the successful hatching of eggs, it is the survival and fledging of these chicks. Further study should include spatial analysis of where fledge rates are the highest and if there are any hot spots in fledging. This can be achieved by sorting and adding the data field of whether a nest had a successful fledge and running the ESHA on those nests. However, one issue with this methodology would be that some broods or chicks move in and out of their territory during the chick rearing stage. Therefore, not being tied to the nesting location habitat factors contributing to the successful fledge would need to be addressed.

6.3 Conclusions

While hot spot analysis in ArcGIS has been used widely in the health care, policing, municipal and utilities industries it has only recently been used in conservation management to identify “hotspots” in environmental data whether it be species, population, or roadside wildlife mortality (Kazemi et al. 2016; McLemore 2017). This study has shown the value of using this tool to determine nesting hot spots and is a good template for other plover breeding sites or analysis on nesting distributions in general. Hot spots in nesting are prevalent at VAFB and should be analyzed yearly to guide management activities and restoration.

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Appendix A. Extract of Plover Nesting Data Post Cleaning

Nest ID	N UTM84	E UTM84	Beach Section	Monitoring Segment	Transect Block	Initiation Date	Date Found	Wrack Index at Initiation	EWF	Week Num	Clutch Size	Clutch Completion	Fate Date	Fate	Pred/ Cause	Days Active
15SAN034	3851276	717205	North	San Antonio	TURTLE	4/27/2015	4/30/2015	0.5	2	18	3	5/1/2015	5/29/2015	Hatched		31
15SAN043	3850853	716925	North	San Antonio	NARROWS	4/26/2015	5/14/2015	0.5	3	17	3		5/27/2015	Hatched		31
15SAN061	3852643	717564	North	San Antonio	DEADBUG	5/25/2015	5/26/2015	0.5	1	22	2	5/27/2015	6/26/2015	Hatched		32
15SAN063	3851575	717183	North	San Antonio	WISHBONE	5/20/2015	5/26/2015	0.5	3	21	3		6/20/2015	Hatched		32
15SAN069	3851858	717270	North	San Antonio	TRASH	5/12/2015	6/1/2015	0.5	3	20	3		6/12/2015	Hatched		31
15SAN080	3851711	717227	North	San Antonio	PICKUPSTIX	6/10/2015	6/10/2015	0.5	1	24	3	6/15/2015	7/12/2015	Hatched		31
15SAN083	3851532	717224	North	San Antonio	WISHBONE	6/11/2015	6/12/2015	0.5	1	24	3	6/15/2015	7/13/2015	Hatched		28
15SAN085	3851749	717362	North	San Antonio	PICKUPSTIX	6/14/2015	6/15/2015	0.5	1	24	3	6/18/2015	7/15/2015	Hatched		31
15SAN088	3850795	716916	North	San Antonio	NARROWS	6/11/2015	6/17/2015	0.5	2	24	2		7/12/2015	Hatched		31
15SAN089	3850933	716950	North	San Antonio	NARROWS	6/14/2015	6/17/2015	0.5	2	24	3	6/18/2015	7/12/2015	Hatched		31
15SAN091	3851172	717052	North	San Antonio	TURTLE	6/14/2015	6/17/2015	0.5	2	24	3	6/18/2015	7/15/2015	Hatched		31
15SAN093	3851483	717166	North	San Antonio	GROSS	6/3/2015	6/17/2015	0.5	3	23	3		7/4/2015	Hatched		31
15SAN094	3851943	717295	North	San Antonio	JUGHEAD	6/6/2015	6/17/2015	0.5	3	23	3		7/7/2015	Hatched		31
15SAN095	3852472	717465	North	San Antonio	TEETER	6/12/2015	6/17/2015	0.5	3	24	3		7/13/2015	Hatched		31
15SAN103	3853556	717687	North	San Antonio	SHSEND	6/13/2015	6/26/2015	0.5	3	24	3		7/14/2015	Hatched		31
15SAN105	3853330	717636	North	San Antonio	L13BUOY	5/30/2015	6/26/2015	0.5	2	22	2		6/30/2015	Hatched		32
15SAN109	3852646	717624	North	San Antonio	DEADBUG	5/29/2015	6/29/2015	0.5	3	22	3		6/29/2015	Hatched		31
15SAN124	3851930	717290	North	San Antonio	TRASH	6/8/2015	8/6/2015	0.5	0	24	3		7/9/2015	Hatched		32
15SHN002	3856151	718188	North	Shuman North	ROLLINGROCK	4/5/2015	4/13/2015	0.5	2	14	2	4/7/2015	5/7/2015	Hatched		31
15SHS005	3855434	718063	North	Shuman South	BUOYFARM	4/24/2015	5/5/2015	0.5	3	17	3		5/25/2015	Hatched		35
15SHS007	3853797	717774	North	Shuman South	TRILOG	5/13/2015	5/14/2015	0.5	1	20	3	5/17/2015	6/14/2015	Hatched		32
15SHS012	3854843	717946	North	Shuman South	OJ	6/12/2015	6/22/2015	0.5	3	24	3		7/13/2015	Hatched		36
15SNO014	3838789	718871	South	Surf North	DRIFTWOOD	4/9/2015	4/9/2015	0.5	1	15	3	4/13/2015	5/14/2015	Hatched		28
15SSO015	3838228	718683	South	Surf South	SQUID	4/28/2015	4/28/2015	0.5	1	18	3	5/2/2015	5/30/2015	Hatched		5
15WAL004	3843262	719708	South	Wall	WALL OPEN	4/3/2015	4/3/2015	0.5	1	14	3	4/8/2015	5/9/2015	Hatched		19
15SAN003	3853364	717672	North	San Antonio	L13BUOY	3/27/2015	3/30/2015	0.5	2	13	3	3/31/2015	4/24/2015	Predated	Unknown	16
15SAN068	3853333	717656	North	San Antonio	L13BUOY	5/28/2015	5/29/2015	0.5	1	22	1		6/2/2015	Predated	Unknown	25
15SAN102	3853564	717701	North	San Antonio	SHSEND	6/22/2015	6/26/2015	0.5	3	26	3		7/11/2015	Predated	Unknown	9
15SAN104	3853502	717676	North	San Antonio	ARROWHEAD	6/25/2015	6/26/2015	0.5	1	26	2	6/27/2015	7/11/2015	Predated	Unknown	4
15SHS010	3855072	717993	North	Shuman South	MINIDUMP	6/9/2015	6/10/2015	0.5	1	24	3	6/23/2015	7/4/2015	Predated	Unknown	4
15SAN010	3852213	717956	North	San Antonio	SHORTRIBS	4/7/2015	4/8/2015	0.5	1	15	3	4/11/2015	4/16/2015	Predated	Skunk	4
15SSO010	3838561	718774	South	Surf South	METEOR	4/12/2015	4/13/2015	0.5	1	15	1		4/16/2015	Failed	Tide	5
15SHN001	3856180	718191	North	Shuman North	ROLLINGROCK	4/2/2015	4/3/2015	0.5	1	14	1		4/6/2015	Failed	Wind	2

Appendix B. Emerging Hot Spot Analysis Categories

(Source: Esri 2018b)

Pattern Name	Definition
No Pattern Detected	There were not hot or cold spot patterns found in area
New Hot Spot	A location that has never been a hot spot before but is a hot spot for the final time step
Consecutive Hot Spot	A location with an uninterrupted run of hot spot bins in the final time-step intervals. Less than 90 percent of all bins are hot spots and the location has never been a hot spot prior to the final run.
Intensifying Hot Spot	A location that has been a hot spot for 90 percent of the time-step intervals including the final interval. The intensity of clustering of high counts in each time step is increasing overall and the increase is statistically significant.
Persistent Hot Spot	A location that has been a hot spot for 90 percent of the time-step intervals with no apparent trend indicating an increase or decrease in the intensity of clustering over time.
Diminishing Hot Spot	A location that has been a hot spot 90 percent of the time-step intervals including the final interval. The intensity of the clustering in each step is decreasing overall with the decrease being statistically significant.
Sporadic Hot Spot	Areas that are hots spots at one time-step interval then not a hot spot. Less than 90 percent of the time-step intervals have been hot spots and never have they been cold spots.
Oscillating Hot Spot	A hot spot for the final time-step interval that has a history of being a cold spot during the prior interval. Less than 90 percent of the intervals have been statistically significant hot spots.
Historical Hot Spot	At least ninety percent of the time-step intervals have been hot spots, but the most recent time period is not hot.
New Cold Spot	A location that has never been a hot spot before but is a hot spot for the final time step
Consecutive Cold Spot	A location with an uninterrupted run of hot spot bins in the final time-step intervals. Less than 90 percent of all bins are hot spots and the location has never been a hot spot prior to the final run.
Intensifying Cold Spot	A location that has been a hot spot for 90 percent of the time-step intervals including the final interval. The intensity of clustering of high counts in each time step is increasing overall and the increase is statistically significant.
Persistent Cold Spot	A location that has been a hot spot for 90 percent of the time-step intervals with no apparent trend indicating an increase or decrease in the intensity of clustering over time.
Diminishing Cold Spot	A location that has been a hot spot 90 percent of the time-step intervals including the final interval. The intensity of the clustering in each step is decreasing overall with the decrease being statistically significant.
Sporadic Cold Spot	Areas that are hots spots at one time-step interval then not a hot spot. Less than 90 percent of the time-step intervals have been hot spots and never have they been cold spots.
Oscillating Cold Spot	A hot spot for the final time-step interval that has a history of being a cold spot during the prior interval. Less than 90 percent of the intervals have been statistically significant hot spots.
Historical Cold Spot	At least ninety percent of the time-step intervals have been hot spots, but the most recent time period is not hot.

Appendix C. WAL and SNO Restoration Areas Hatched HSA

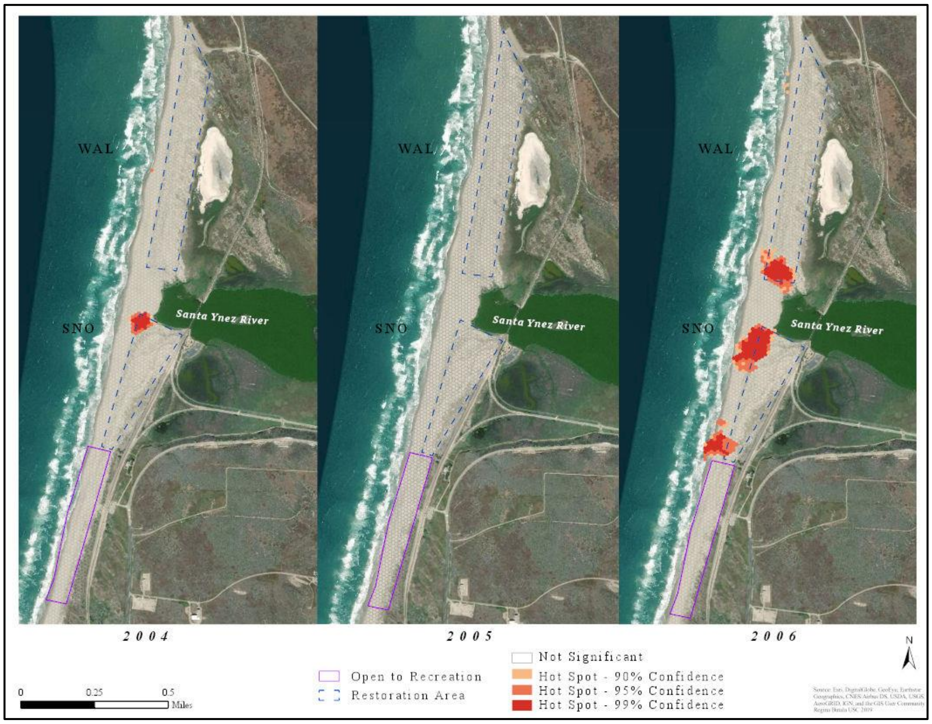

Figure 38. WAL and SNO Restoration Areas Hatched HSA 2004-2006.

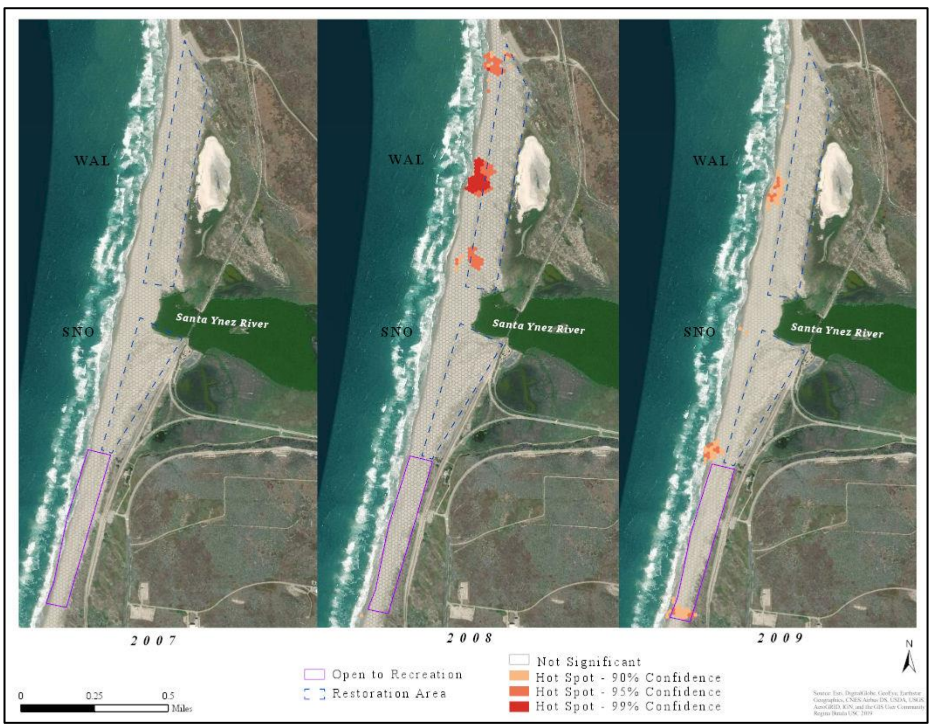

Figure 39. WAL and SNO Restoration Areas Hatched HSA 2007-2009.

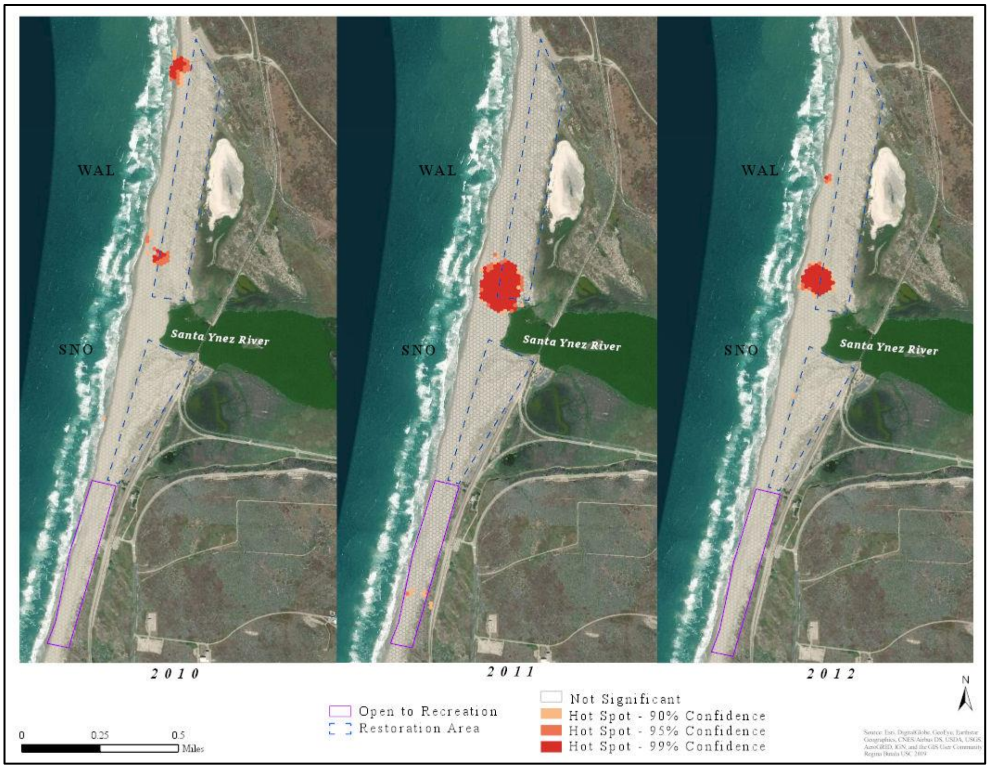

Figure 40. WAL and SNO Restoration Areas Hatched HSA 2010-2012.

Figure 41. WAL and SNO Restoration Areas Hatched HSA 2013-2015.

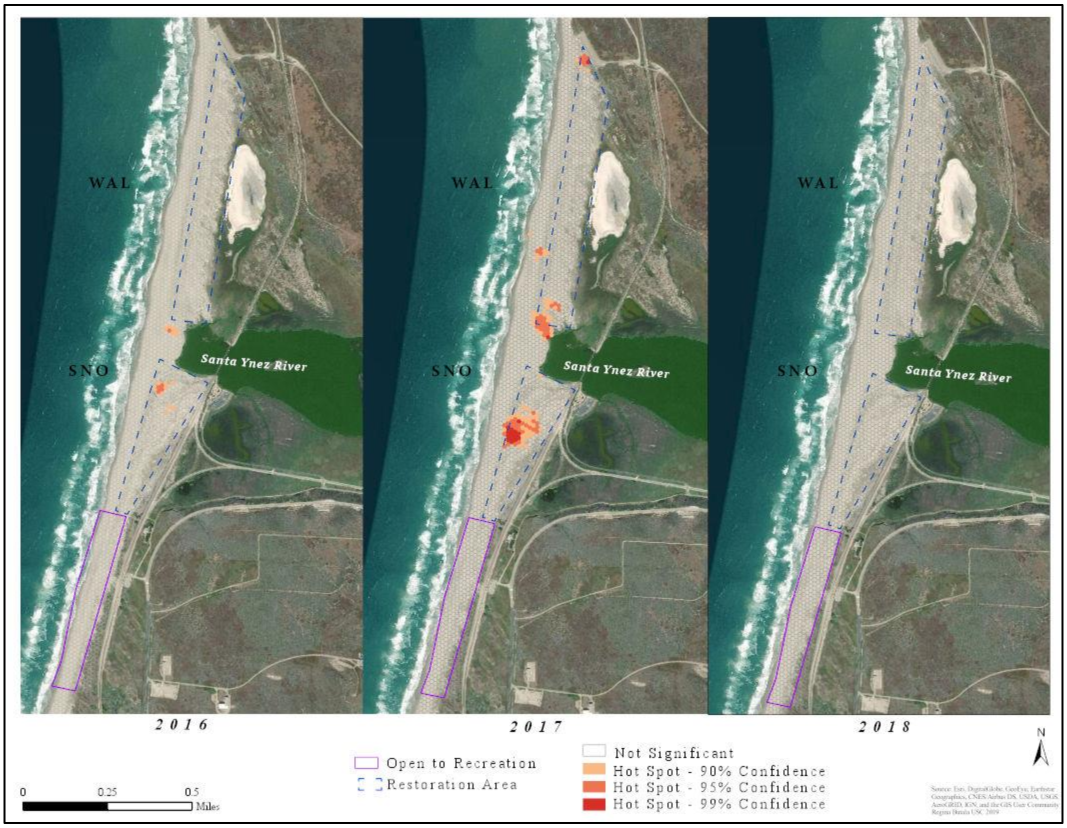

Figure 42. WAL and SNO Restoration Areas Hatched HSA 2016-2018.

Appendix D. STC Hot Spot Visualization Hatched and Predated

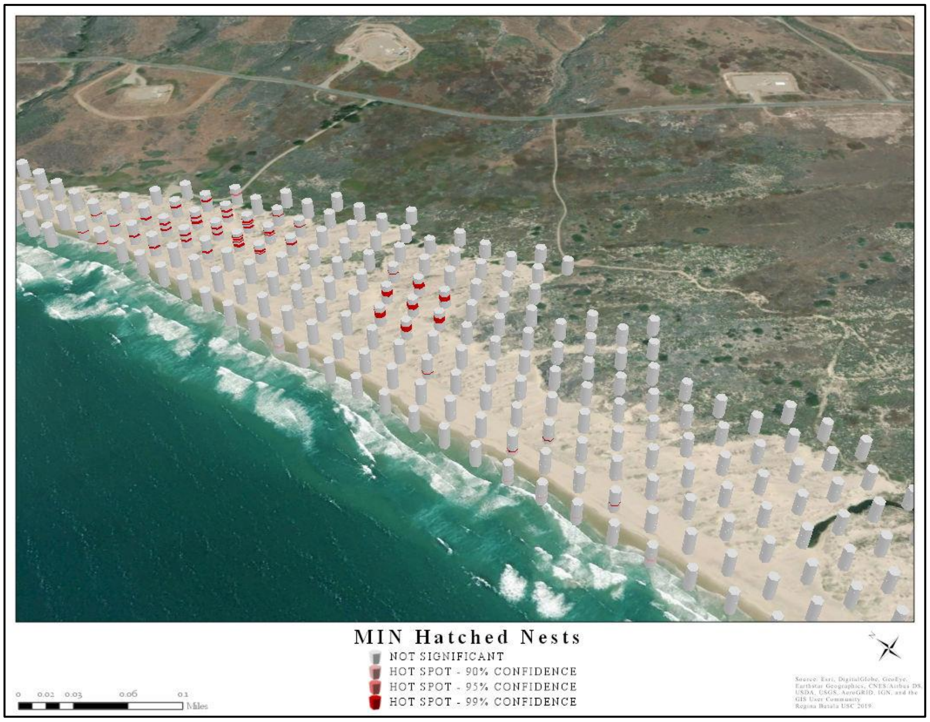

Figure 43. MIN – STC Hatched Nest Hot Spot Visualization.

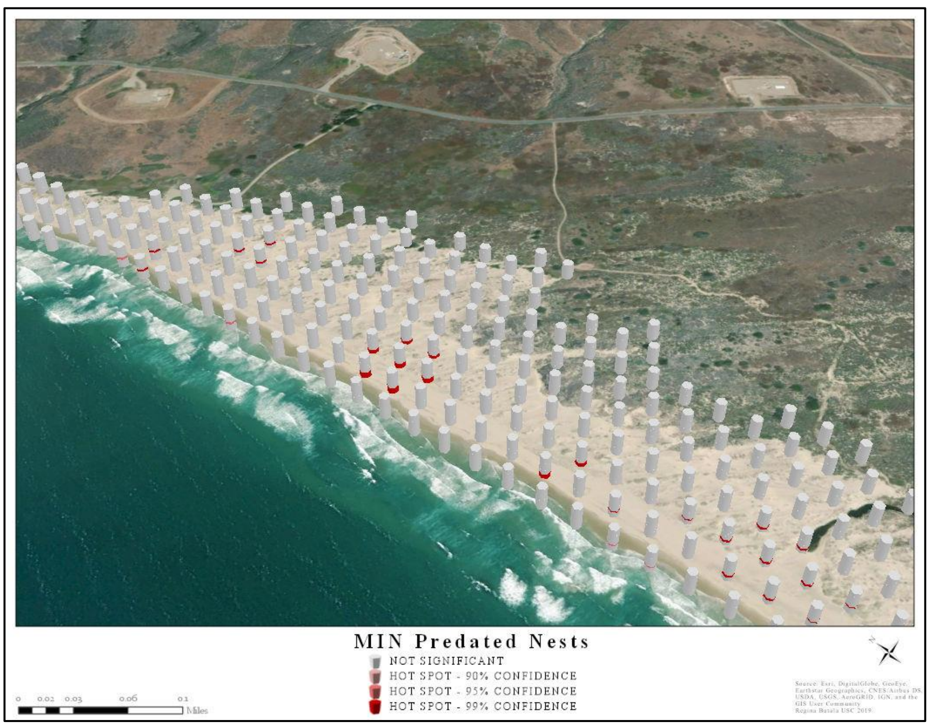

Figure 44. MIN – STC Predated Nest Hot Spot Visualization.

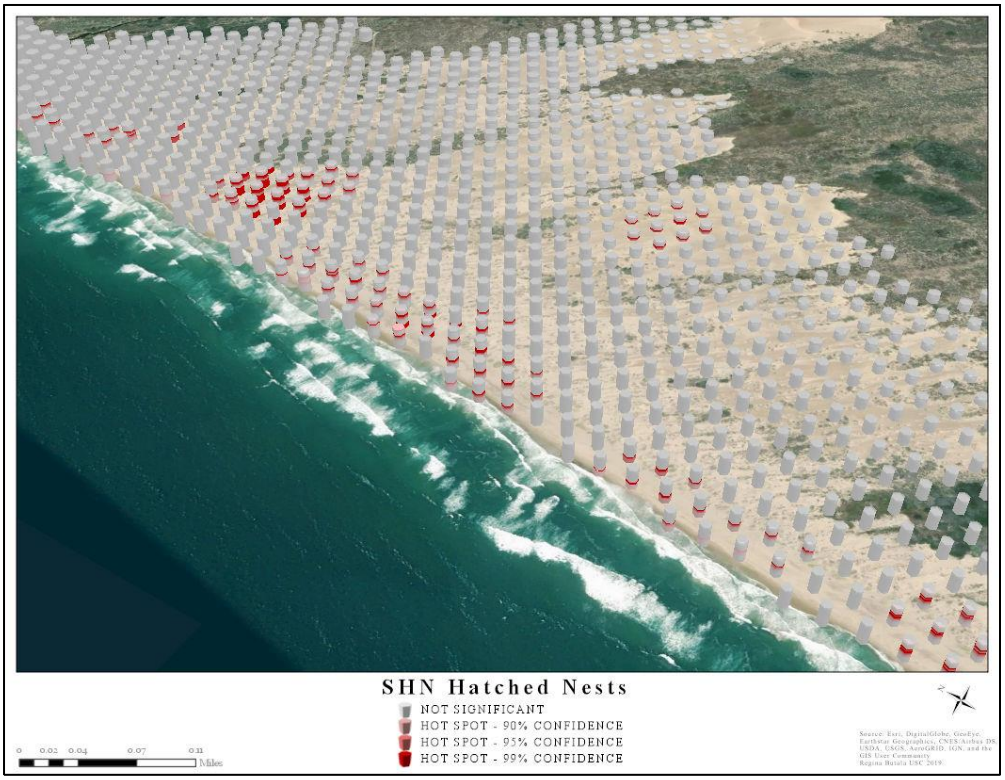

Figure 45. SHN – STC Hatched Nest Hot Spot Visualization.

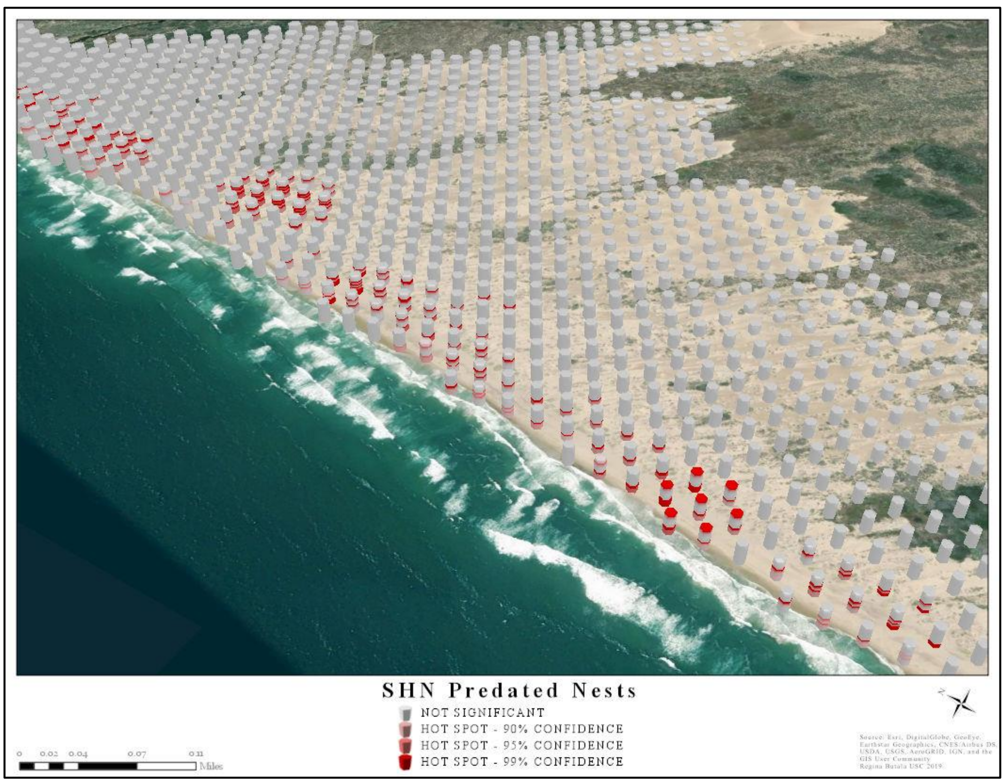

Figure 46. SHN – STC Predated Nest Hot Spot Visualization.

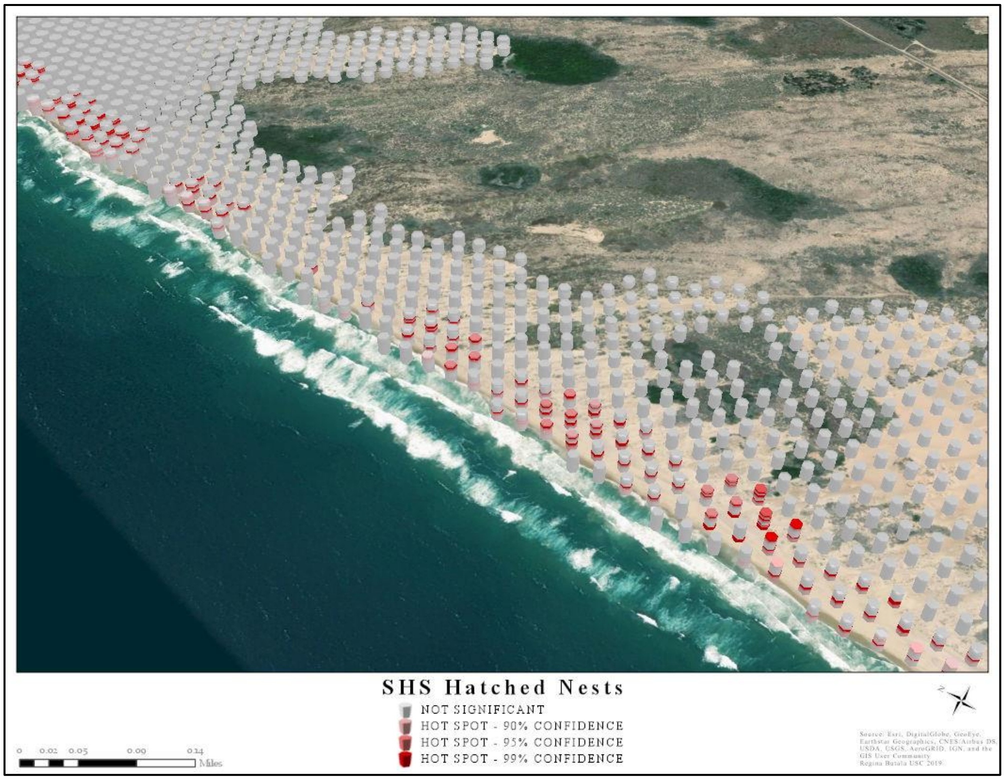

Figure 47. SHS – STC Hatched Nest Hot Spot Visualization.

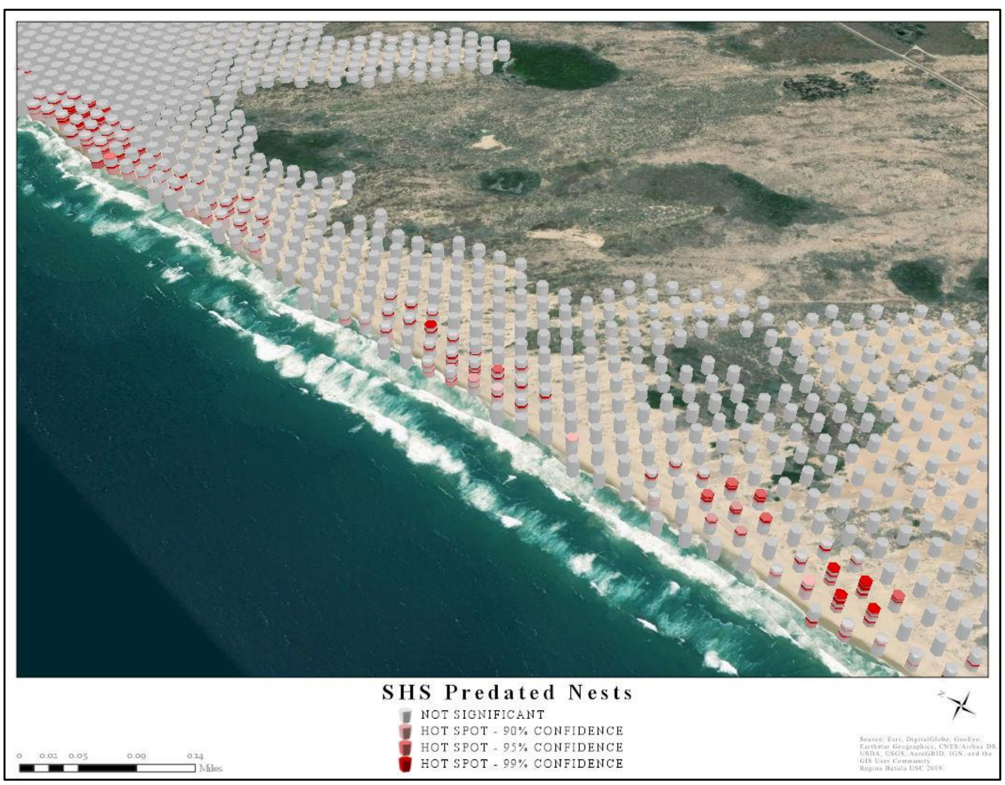

Figure 48. SHS – STC Predated Nest Hot Spot Visualization.

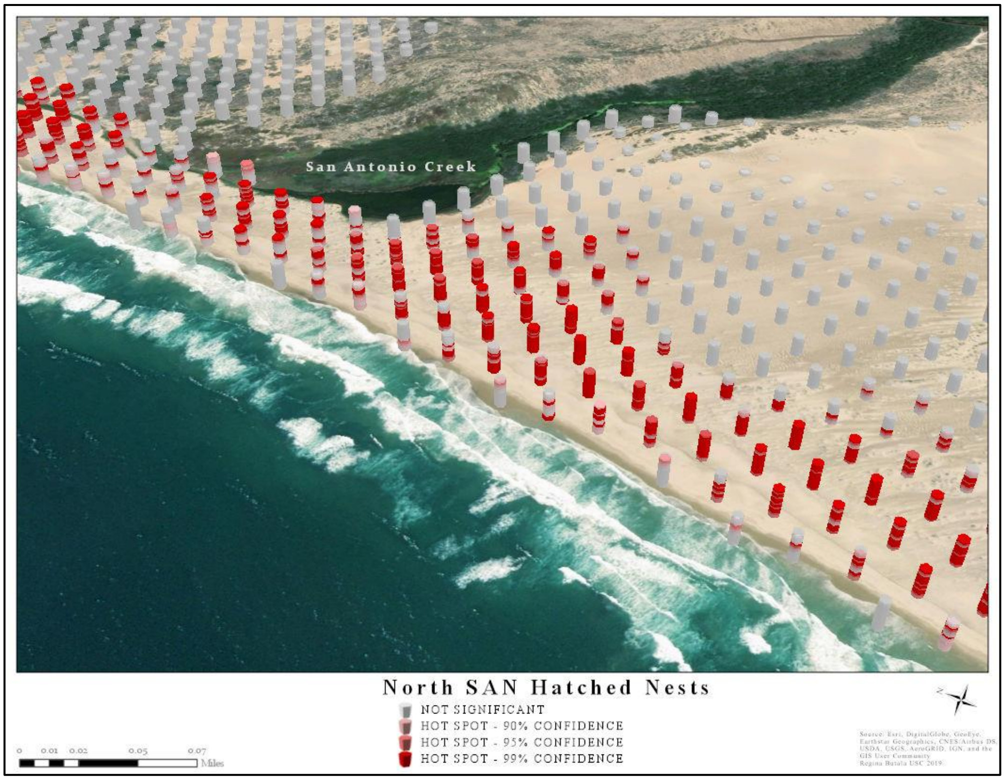

Figure 49. North SAN – STC Hatched Nest Hot Spot Visualization.

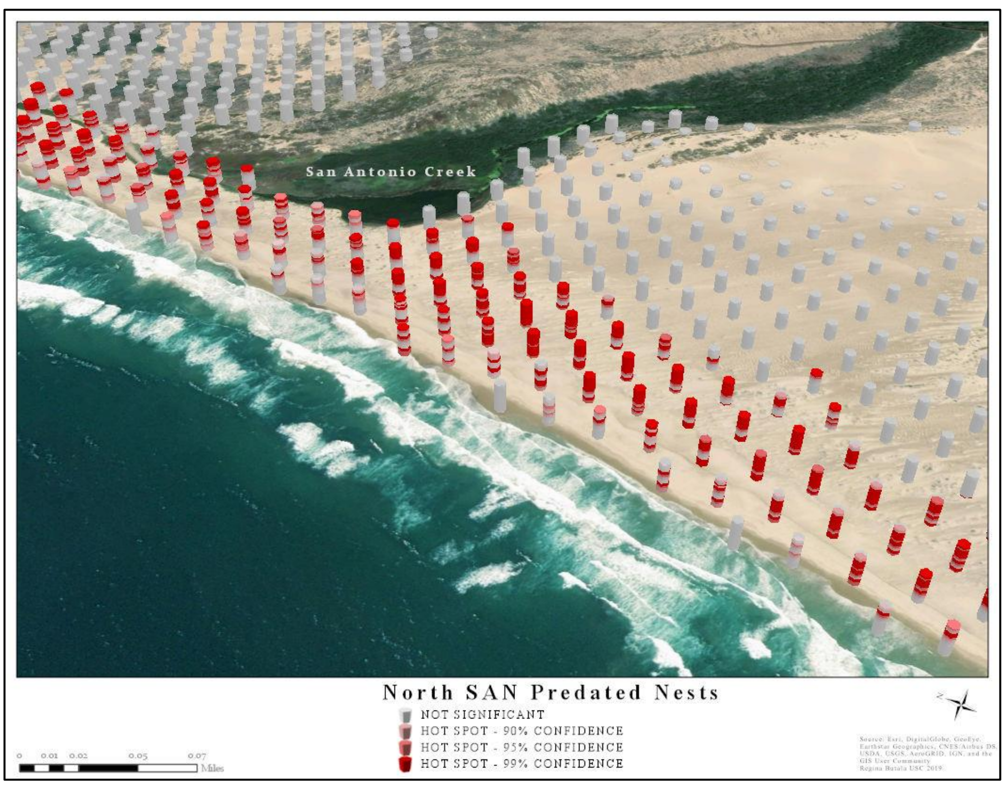

Figure 50. North SAN – STC Predated Nest Hot Spot Visualization.

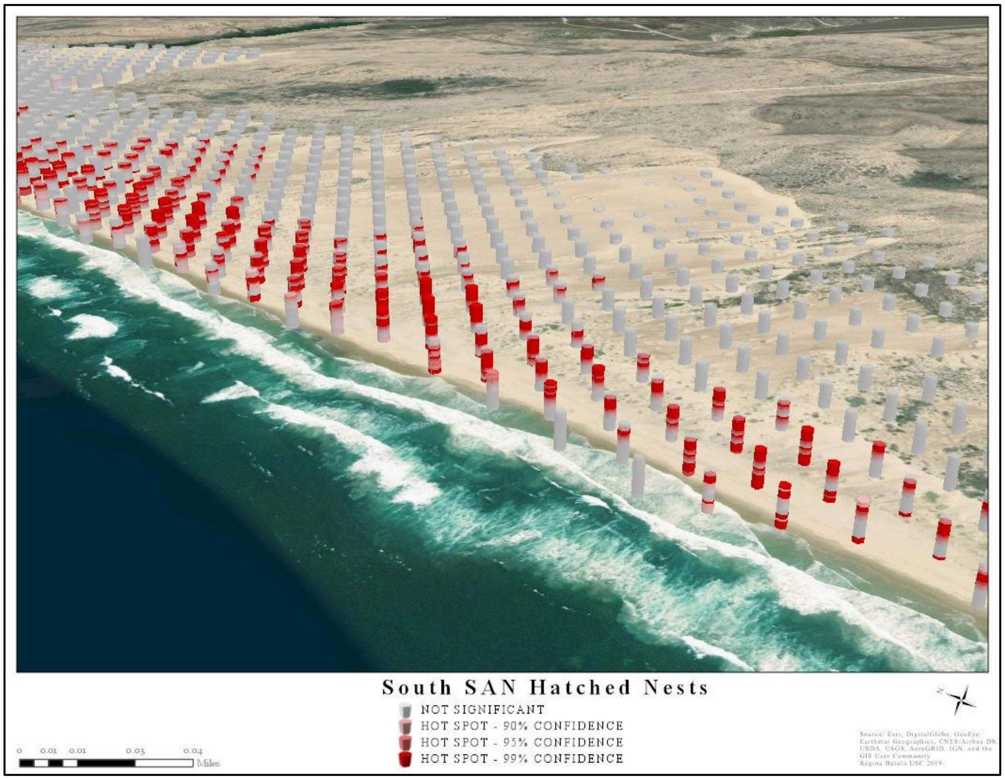

Figure 51. South SAN – STC Hatched Nest Hot Spot Visualization.

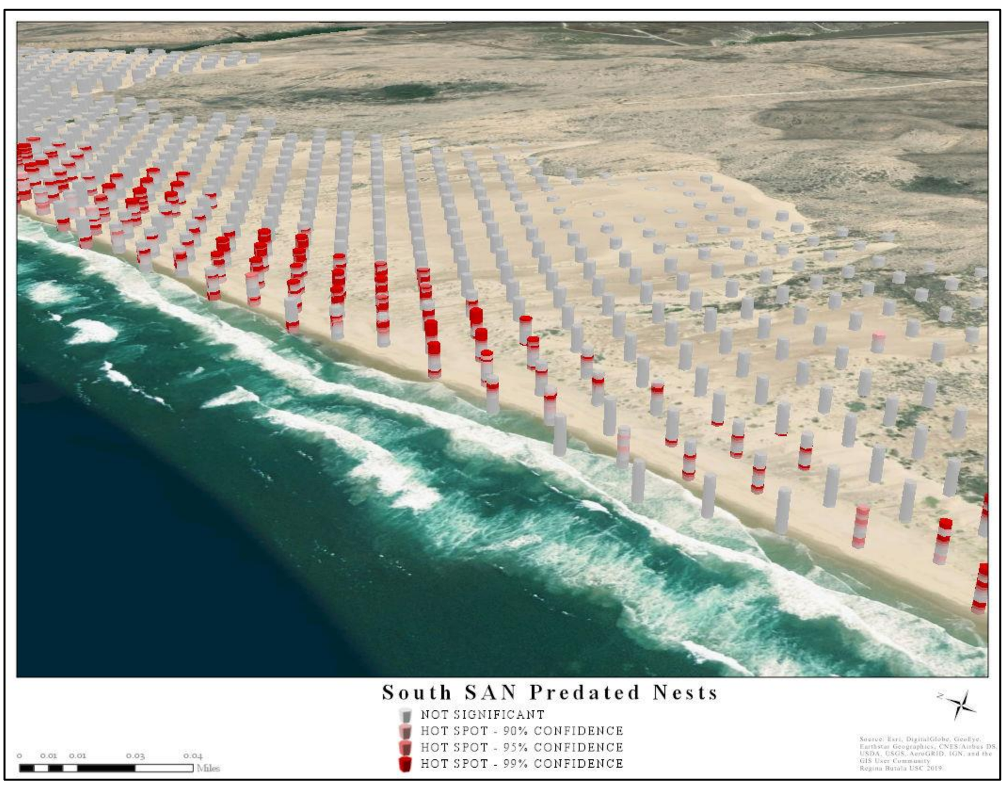

Figure 52. South SAN – STC Predated Nest Hot Spot Visualization.

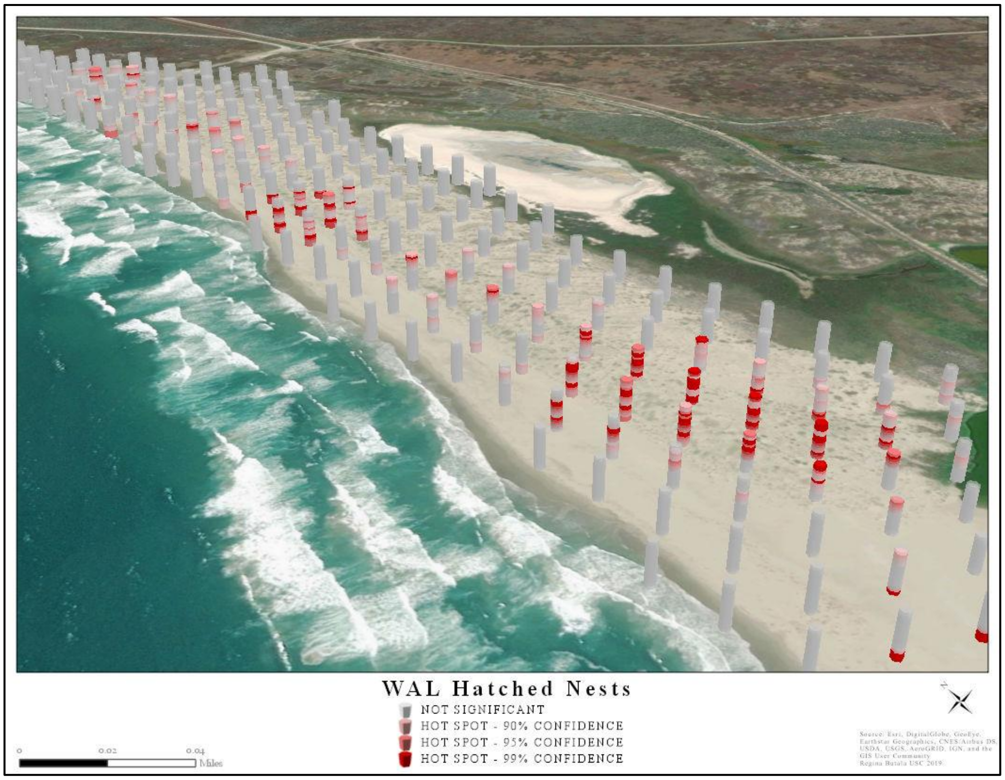

Figure 53. WAL – STC Hatched Nest Hot Spot Visualization.

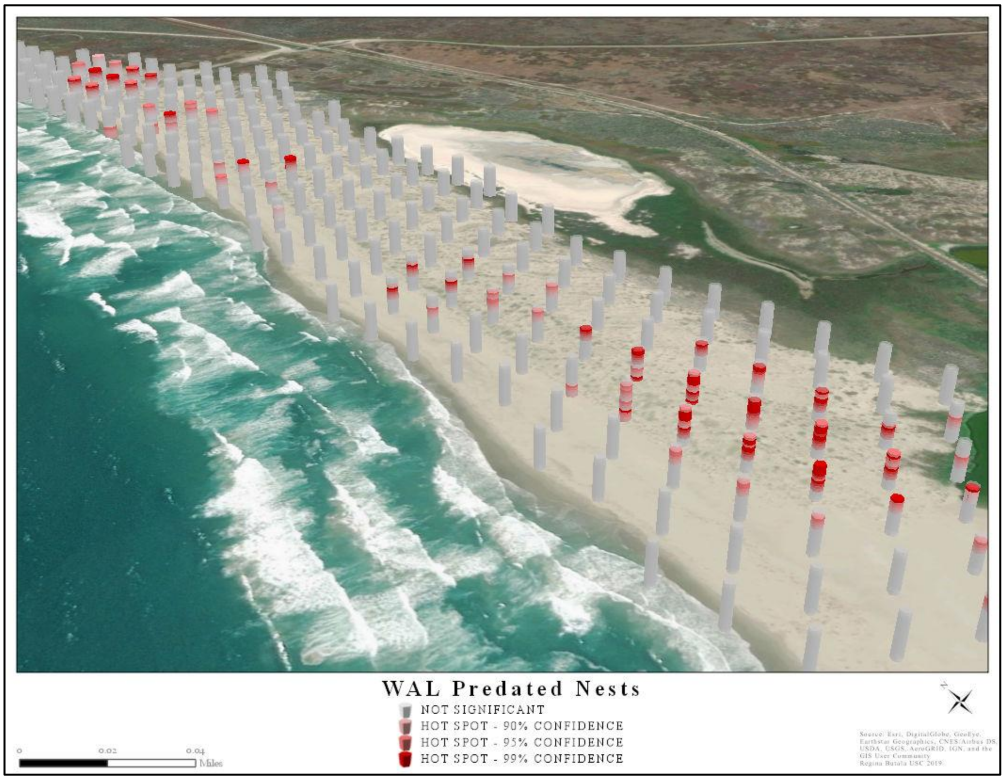

Figure 54. WAL – STC Predated Nest Hot Spot Visualization.

Figure 55. North SNO- STC Hatched Nest Hot Spot Visualization.

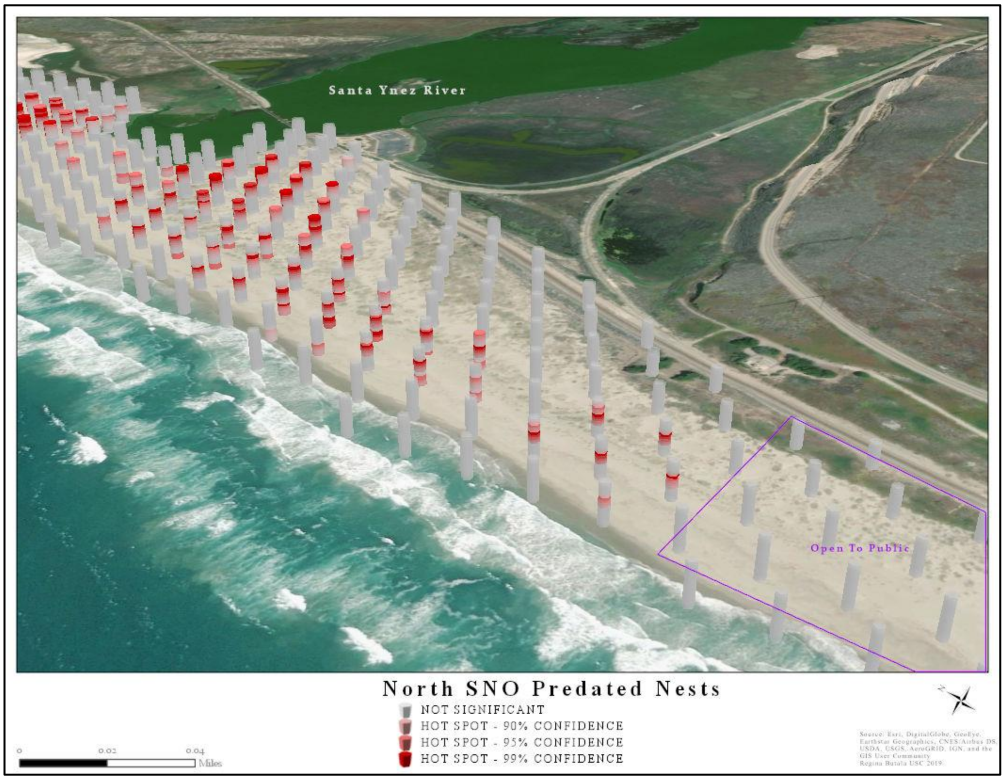

Figure 56. North SNO – STC Predate Nest Hot Spot Visualization.

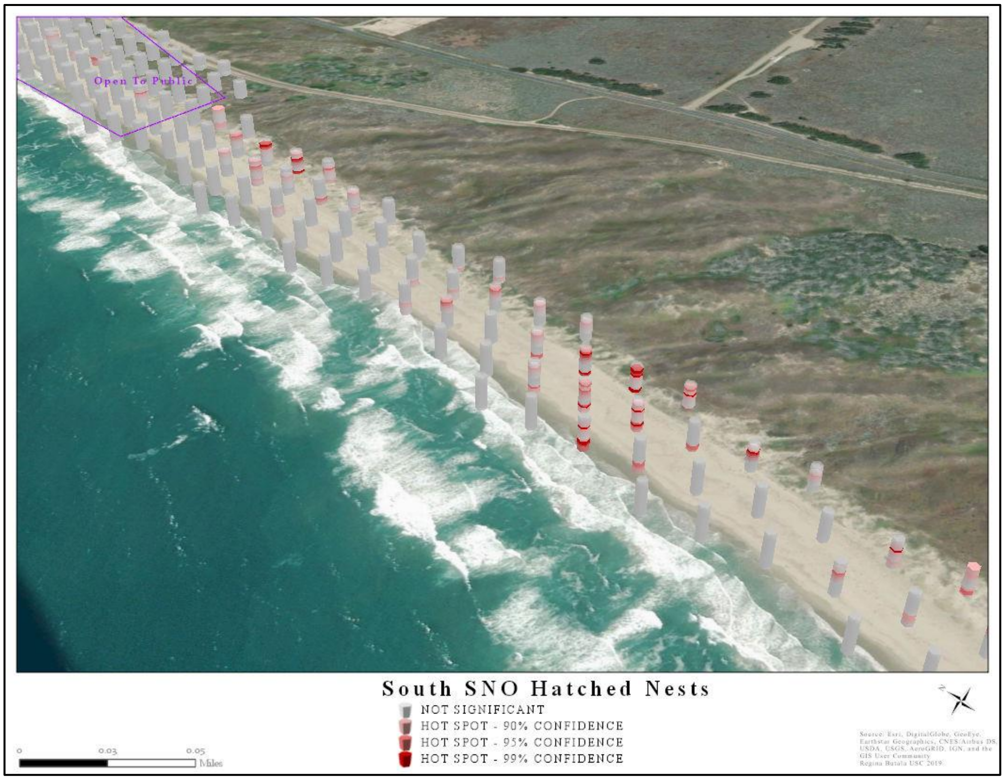

Figure 57. South SNO – STC Hatched Nest Hot Spot Visualization.

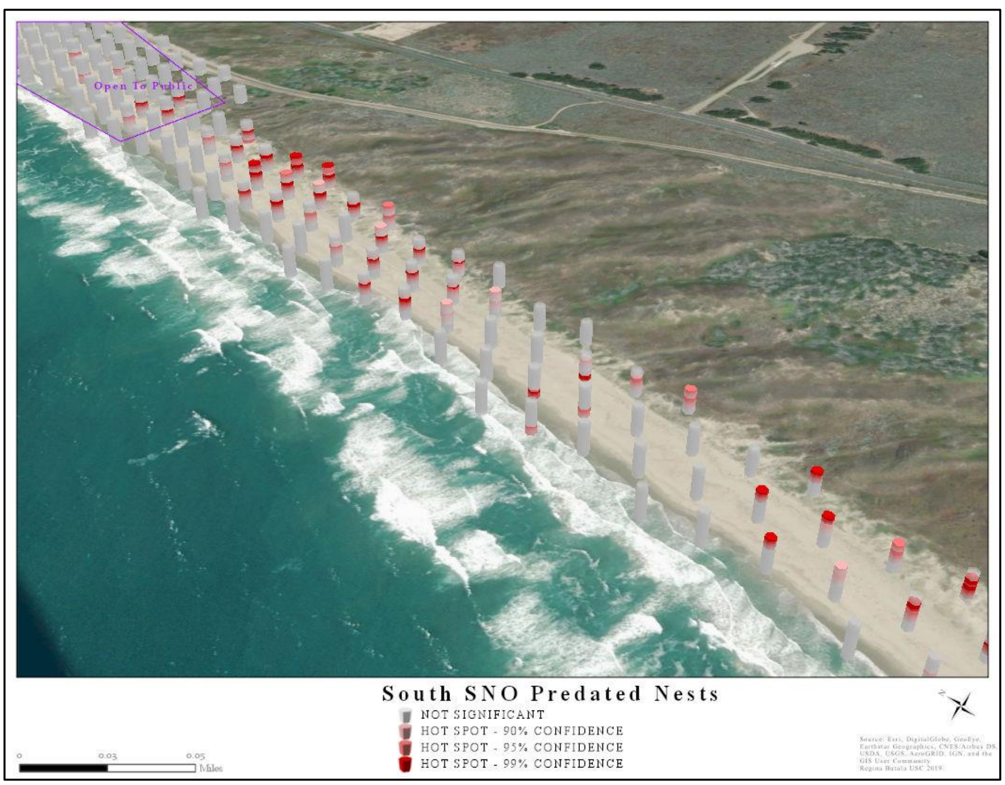

Figure 58. South SNO – STC Predated Nest Hot Spot Visualization.

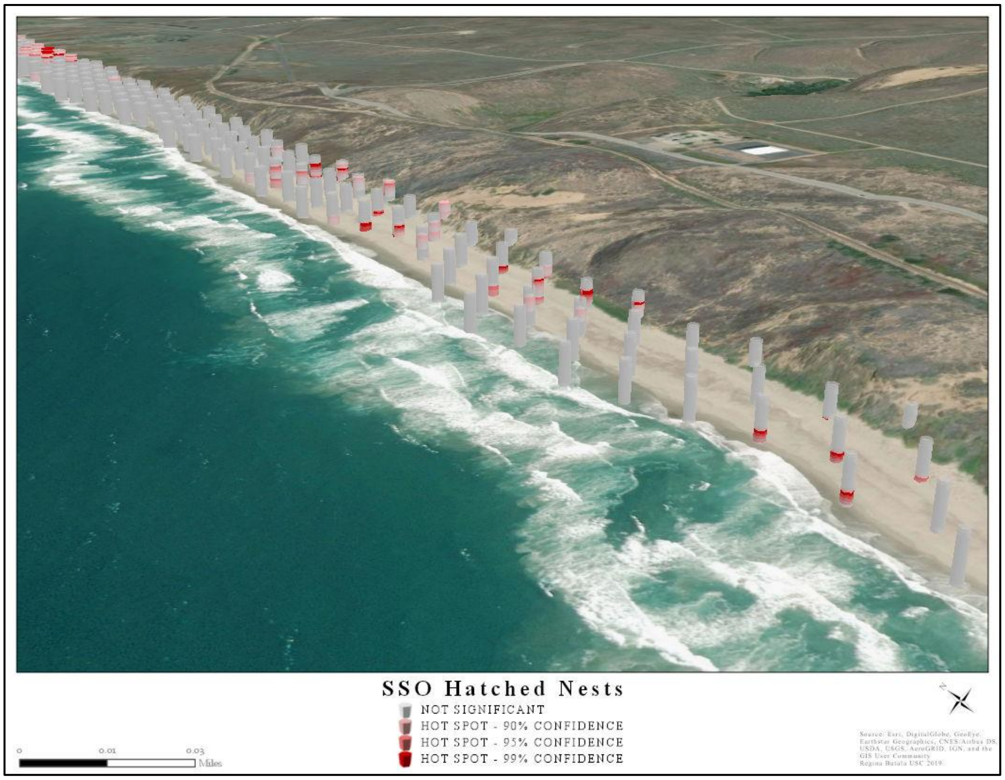

Figure 59. SSO – STC Hatched Nest Hot Spot Visualization.

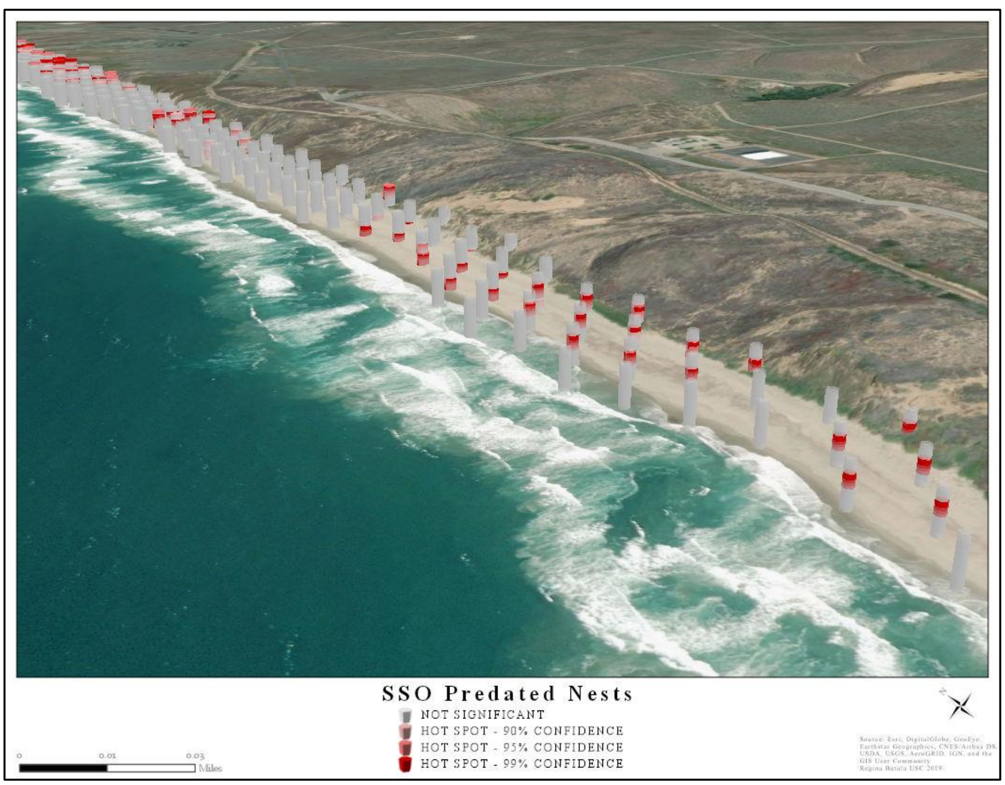

Figure 60. SSO – STC Predated Nest Hot Spot Visualization.