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Spatial Analysis of Common Raven Monitoring and Management Data for

Desert Tortoise Critical Habitat Units in California

A thesis submitted in partial fulfillment of the requirements for the degree of Master of

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By

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Abstract

Common Ravens (*Corvus corvax*) are a native species in the Mojave Desert, but their populations have increased throughout the years due to resources provided by humans (ex. landfills, agriculture, standing water etc.). Increased densities of Ravens may have negative impacts on endangered or threatened species, such as the Desert Tortoise (*Gopherus agassizii*). We want to understand the Raven aggregations with respect to both anthropogenic and natural subsidies and their impacts on tortoise population. We have developed statistical models to provide spatial context to Raven nest density, nesting preferences, nesting success, and characteristics of offending nests throughout the Desert Tortoise Critical Habitat Units (CHU) in California. We analyzed nest survey data collected for nests on both anthropogenic and natural substrates using a variety of spatial methods to reduce autocorrelation bias, including spatial bootstrapping comparisons with null models, point process models, and geostatistical analyses. We found that nests on natural substrates tend to be located in areas that are have high Desert Tortoise suitability values, closer to agriculture, and in rougher terrain. Nests placed on anthropogenic substrates are more prominent in areas with high Desert Tortoise habitat suitability and closer to seasonal water resources. Fledgling success for both anthropogenic and natural nests were inversely correlated with temperature at the beginning of breeding season. We found negative effects on nest success relative to whether a nest was offending, indicating that these nests tended to be in areas with a suite of conditions that reduced success, and that the addition of tortoises into Raven diets did not in fact appear to improve the likelihood of success. This work will increase our understanding of the potential influence of anthropogenic features and subsidies in the desert, provide a spatial context

on Raven threats to Desert Tortoise populations, and may have the potential to improve

management tools and practices in managing Raven populations, which may ultimately

aid in recovering Desert Tortoise populations.

Dedication

I would like to dedicate this to my parents:

Kia V. Xiong and Wawoo Xiong.

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Thanks to all my committee members for their time, advice, and guidance throughout this entire study. I would like to especially thank Dr. Kenneth Nussear for giving me the opportunity to grow as a researcher, biogeographer, and as a person. Also, many thanks to my lab members and cohort. I wouldn't have been able to get through this without any of you.

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Chapter 1: Nesting ecology and diet diversity for breeding populations of Common Raven *(Corvus corax)* throughout California's Desert Tortoise Critical Habitat Units

<u>**Introduction**</u>

Common Ravens (*Corvus corax*) have long been considered one of the important predators contributing to the collective threats imparting pressure on Desert Tortoise (*Gopherus* agassizii) populations (Berry 1986, USFWS 1994, Tracy et al. 2004). The Raven is a native species in the Mojave desert ecosystem (USFWS 1994), but Raven population levels have become elevated by subsidation from human activities as they moved into the western United States, vastly expanding the human footprint, and it's influence on native ecosystems (Boarman 1993, Kristan and Boarman 2003, Leu et al. 2008). As Ravens can aggregate in areas with subsidies (e.g. landfills) where their local populations increase, they can have spatially focused areas of influence (Kristan and Boarman 2003), although the presence of Ravens does not always result in elevated predation levels (Bjurlin and Bisonette 2004). The human footprint in the desert is also typified by the expansion of roads and power transmission lines, which not only fragment and degrade habitat (Leu et al. 2008), but also provide additional opportunities for subsidation by way of nesting substrates (e.g. power poles and towers) that are readily used by Ravens, and provide comparable nesting success to that of natural nesting substrates (Steenhof et al. 1993).

Understanding the role of human caused subsidies on population dynamics is crucial for effective species management as it provides mechanisms to control the

increase of predator populations on threatened species such as the Desert Tortoise. In 1990, the Desert Tortoise was federally listed as a threatened species (GAO 2002). Desert Tortoises are a long-lived species with slow growth, and delayed maturity, which are life history traits that show slow recovery rates to disturbances that reduce population numbers (Turner et al. 1987). The United States Fish and Wildlife Service [USFWS] described and reviewed threats to the Desert Tortoise noting that habitat loss, fragmentation, and Raven predation were driving forces to the decline their populations (USFWS 1990, 2011b). Critical habitat units (CHU) throughout Mojave Desert were designated as part the recovery plan for the Tortoise, creating large "reserves" within which recovery is managed for. The 14 CHUs are located in four southwestern states, including portions of Arizona, California, Nevada and Utah. The sizes of the areas were based on estimated tortoise population densities, vegetation, and estimated tortoise home range, which resulted with a total of 14 areas containing over 24,200 km2 (GAO 2002).

Ravens are natural predators of many species, including Desert Tortoises. However, as Raven populations continue to increase, Desert Tortoises experience higher predation risk (Kristan and Boarman 2003). Ravens prey on hatchling and juvenile tortoises (Esque and Duncan 1985, Boarman 1993) by pulling at heads and limbs, pecking holes through the soft carapace (top of shell), and by flipping tortoises over and pecking at their plastrons (bottom half of shell). Although it is less common, observations of predation on adult tortoises have been reported as well (Esque et al. 2010). Survivorship in Desert Tortoises increases with body size and age, and tortoises are more susceptible to Raven predation until they are approximately nine years old, or 100 mm in length (Boarman and Heinrich 1999, Turner et al. 1987). To aid Desert Tortoise recovery,

it is important to understand population increases in Common Ravens and the associated threat to Desert Tortoises. There are many studies on Raven populations in habitats that contain endangered or threatened species or protected areas (Coates et al. 2014, Howe et al. 2014, Scarpignato and George 2013, West et al. 2016). However, there has been relatively little research conducted toward understanding, preventing, and monitoring Common Raven predation on Desert Tortoise Critical Habitat Units throughout California (Boarman 2003).

This study investigates how anthropogenic subsides affect the spatial distribution of Raven nests, and subsequent Raven predation on tortoises during the nesting season. Here we use an extensive USFWS dataset to provide an analysis of nesting density - with respect to nests on both natural and anthropogenic substrates, and we create a map of predicted nesting density based on environmental parameters that may reflect the potential for subsidy, and climatic conditions throughout the region. I then use Raven distribution data to assess apparent Desert Tortoise predation by nesting Ravens, and identify which conditions/locations are likely to result in increased levels of predation. Finally, I provide information on Raven diets throughout the critical habitat units and asses the relationship of diet to place as well as desert tortoise habitat suitability.

Methods

Survey Area

The Mojave Desert ecosystem encompasses a vast area of 127,689 km^2 in the southwestern United States, of which approximately 37 percent is considered critical habitat for the Desert Tortoise in California (GAO 2002, Nussear and Esque 2019). Eight

of the fourteen Desert Tortoise Critical Habitat Units (CHUs) are located in California, including: Chuckwalla, Fremont-Kramer, Ord-Rodman, Joshua Tree/ Pinto Mountains, Superior-Cronese, Piute-Fenner, Chemehuevi, and Ivanpah (Figure 1). Collectively these areas represent a broad array of habitats for the Desert Tortoise. The elevation within the CHUs ranges from an elevation of 800 meters (e.g. Ivanpah) to 1,200 meters (e.g. Superior-Cronese), although tortoise habitat more generally has a wider range (Nussear and Tuberville 2014), and the CHUs are not evenly composed of suitable tortoise habitat throughout (Nussear et al. 2009). Vegetation also varies from site to site but contains common desert flora such as Creosote/Bursage desert scrub, mixed Mojave Desert scrub with Joshua trees, and other yucca species. The Critical Habitat Units contain areas spanning both the Mojave (in the northern CHUs) and the Colorado subdivision of the Sonoran Desert (in the southern CHUs), and landforms including mountains, desert washes, and cliffs are also common throughout the desert. Temperatures in the Mojave and Sonoran Deserts range with mean annual temperatures ranging from -2 ℃ in winter to daytime highs of 43 ℃ in summer, with annual precipitation ranging from 80 mm to 180 mm (Hereford et al. 2006, Nussear and Tuberville 2014).

Survey Methods (based on NFWF RFP 2013- 2018)

This study analyzed the USFWS Raven Monitoring and Management Dataset collected by several contractors (Bajada Ecology, LLC., Conservation Science Research & Consulting, Corvus Ecological Consulting, LLC., Hardshell Labs, Inc., and Sundance Biology, Inc.) who implemented Raven monitoring plans for the Bureau of Land Management (BLM) and United States Fish and Wildlife Service (USFWS).

Field surveys were intended to maximize Raven observations during nesting

season (March-July), and each team was tasked to target an entire critical habitat unit in each year. Upon identifying a potential or active Raven nest, subsequent monitoring of the site was conducted based on a pre-defined monitoring schedule, which was used throughout all years of monitoring (2013-2018, Table 2).

Sampling of powerlines interconnected with roadways were prioritized for surveys, as this yielded the largest associated number of nests per unit effort. Surveys were conducted during daylight hours (45 minutes after sunrise and 45 minutes prior to sunset) by slowly driving on established open routes and BLM designated open routes, no more than 20-25 miles per hour on dirt roads within identified priority areas (Corvus 2013, Boarman and Boarman 2014). Transmission lines took precedence in surveying during the early monitoring season (March-April), with emphasis on nest locations that have been identified in previous years. Surveys of areas known to provide substrates for natural nests (such as trees or cliffs) that were difficult to reach were minimized, and were surveyed only after searches of anthropogenic substrates (such as transmission poles, signs, or buildings) were completed. Not surprisingly, this prioritized survey effort created a spatial bias in the observations toward transmission lines and roads, where nest densities seem - and are expected to be highest, with less information gathered about the locations of natural nests, and without a complete inventory of potential natural nesting areas.

Observations of Ravens and nest sightings were conducted at a distance using binoculars or a high-powered spotting scope. All Raven nests were monitored for a minimum of 20 minutes until nest status (i.e. active, inactive, completed, failed, or no activity) was determined.

Data identifying Raven nests were collected within each California CHU spanning six years (2013-2018), although not all sites were surveyed in all years (Table 3). Surveys were repeated at each of the CHUs annually, spanning from 1 to 4 years (Table 3).

This study consisted of two phases to date. The first phase involved only monitoring actions, involving locating new and old nests and observing those that showed signs of activity, as well as taking note of any evidence of tortoise predation. The second phase resulted in management efforts, as well as continued monitoring. This meant that egg oiling (a method of halting egg development) and nest removal efforts were conducted at CHUs where 10% of the nests had evidence of tortoise predation (Table 3). A third phase will be included in future management efforts, which will consist of the removal of Ravens from concentrated areas (such as landfills) through actions taken by Wildlife Services. Also note, that these phases build upon each other so that all actions are performed for each increasing phase (e.g. monitoring is not stopped after phases II and III are implemented).

When nests were located, pertinent data were recorded describing the nest site, including: nest location (easting and northing); month, day, and year of nest observation; breeding/developmental stage; numbers of eggs, hatchlings, fledglings, and adults in the nest; and nest substrate type (trees, cliffs, transmission poles etc.). The breeding/developmental stage information included: courtship/copulation, nest building, incubation, hatchling/nestling, fledgling, nest cycle complete/fledged, failed, undetermined, unoccupied, destroyed/does not exist, unable to locate, and wildlife service visits. Breeding/developmental stage information were used to determine if a nest was

active, the final outcome of the nest, and if a nest was "offending" or not.

We defined an "offending" nest as one that has evidence of predation or consumption of Desert Tortoises. Surveys to identify whether nests showed evidence of predation on tortoises were conducted using circular plots with a 10-meter radius placed directly beneath nest sites. Survey crews searched for Raven pellets (undigested materials that are coughed up by Ravens and other birds) or evidence of tortoise remains under each nest. Opportunistic surveys for potential perch sites or tortoises could have also occurred beyond the 10-meter plot, with a limit at 300 meters, although observations with these nests could not be associated with specific nests. If pellets were found within or near the circular plot, a quick assessment of contents was typically carried out in one of two methods: 1) crushing the pellet in a bowl or 2) soaking the pellets in water and viewing contents with a hand lens. Raven pellet data contained information on pellet location, nest association, pellet content (mammal, insects, tortoise, others), age of pellet (fresh, old), and number of pellets found. Although, nest association and locations were not always recorded with the pellet information. We classified nests with tortoise carcasses and/or pellets containing tortoise remains as offending.

If tortoise carcasses were found near nests, a rough estimate of 'time since death' and size were recorded. Remains were then removed from the site, crushed, and buried away from the plot. A positive identification of remains associated with a Raven nest would result in notifying USDA APHIS - Wildlife Services (WS) or a USFWS contact of the offending nest. This sometimes resulted in a management action of removing the nest, all nestlings, and/or offending Ravens. Continued monitoring by the survey team was conducted post removal. Management actions (phase 2, Table 3) may indicate a less than

sufficient drop in Raven predation pressure on the Mojave Desert Tortoise population and Raven nest success. Cross referencing between the nest dataset, pellet dataset, and carcass dataset was conducted in order to confirm classification of offending nests.

Egg Oiling Method

Sundance Biology, Inc. and Hardshell labs, Inc. (2018) created a nest oiling decision tree (Figure 2) to help determine a course of action based on nest development stages. Only nests found on natural substrates were oiled (although the use of drones to oil transmission tower nests is now being implemented). Known natural substrate nests from previous monitoring years were visited in early April. New natural substrate nests were also monitored. Nests with a full clutch (3 or more eggs) were oiled, revisited, and actions were taken based on the decision tree (Sundance Biology, Inc. and Hardshell labs, Inc. 2018). The oil used in Superior-Cronese and Chemehuevi was Clearco SP-5, a silicone-based food grade oil. The oil was delivered through a fluid application system (FAS) carried either on an Unmanned Aerial Vehicle (UAV, i.e. drone) or a telescoping pole, each with an attached camera. More studies are being conducted on the effectiveness of egg oiling on subsidized predatory avian species (Shields et al. 2019).

Five of the CHU's have moved into phase two of the Raven management project, Superior-Cronese, Chemehuevi, Chuckwalla, Joshua Tree National Park/Pinto Mountains, and Ord-Rodman (Table 2). Egg oiling treatments occurred in Superior-Cronese, Chemehuevi, Joshua Tree NP/ Pinto Mountains, and Ord-Rodman (Table 2). After removals or oiling, monitoring continued until the nest was confirmed as successful or failed; and whether additional tortoise carcasses were deposited.

While similar data were collected in each CHU for each year that it was surveyed,

data collection for each dataset was not entirely consistent among CHUs or among years

that surveys were conducted. Data collected also differed among survey teams. Each

survey team had their own data format and field definitions, but generally followed the

same survey protocols, guidelines, and recommendations from NFWF, USFWS, BLM,

and USDA APHIS-WS (Table 1). Because the different survey efforts did not use a

common data dictionary, we created standardized columns for each key variable for

analysis (supplementary item).

Data Summary

We summarize the Nest Dataset in Table 4. There were a total of 5,229 nests

visited by surveyors between 2013 and 2018. These visits included nests that were

"unoccupied", "unknown" (unidentifiable species that occupied a nest), non-Raven nests

(e.g. those of Red Tailed Hawks or other raptors), and those classified as Raven nests

(Table 4, col. 3). For the rest of the analyses and summary here, we only use "active"

nests (n= 1,449) that were occupied by Ravens. We defined "active nests" as those for

which the data for nest development stages were recorded as: copulation, incubating, nest

building, active, fledged, or complete. All of these stages were considered because there

were incidences where the first few nest visits had no nest activity, and by the last visit

the nest was "complete". If data were not available for that field, we used information

from the comments to infer our decision if a nest would be considered active. We

analyzed Raven nest density and nest site selection from a total of 1,449 unique nesting

sites among all years in California's Desert Tortoise CHU between the years of 2013 and

2018 (Table 4, col. 4). We considered a nest to be unique by location and year. To reduce

spatial autocorrelation, nests that were within 5 meters of one another and found on the

same year were labeled with the same ID. For example, if 3 nests were found on one transmission pole, then all three nests had the same ID. If a nest was found in an area in 2017, and then the same nest was found in the same location in 2018, those would be considered two unique nests, as they represent different nesting events, and we cannot know if the same pair of Ravens initiated the nesting event for any given year.

There were 1,449 confirmed active Raven nests, with 815 of those nests considered successful (56%, Table 4 cols. 3 and 7), and about 12 percent of those active nests were considered to be offending (Table 5). According to Table 2, a confirmed active Raven nest with tortoise remains located near the nest would result in coordinating with WS. Coordination should have led to the decision to remove offending ravens, nests, or hatchlings; however, not every offending nest that was identified was coordinated with WS. Also, WS for Raven removals/actions and oiling practices were not conducted for all sites and all years. WS removals/actions were counted as "attempts", because WS would visit the same nest site more than once. Removal/action attempts were generally successful, with only 25 out of 199 nest sites (13%) were considered successful post intervention, mostly due to re-nesting or inconsistency within the dataset (Table 6, cols. 3 and 4). Oiling nests resulted in zero nest success (Table 6, cols. 5 and 6). Each oiling and removal attempt was revisited by surveyors to confirm nest fate.

To facilitate analyses with sufficient samples for broader predictive ability, while accounting for regional effects, the eight CHUs were split into three groups proximal to one another: East CHUs (Ivanpah, Piute Fenner, and Chemehuevi), West CHUs (Superior-Cronese, Fremont-Kramer, and Ord-Rodman), and South CHUs (Pinto Mountains and Chuckwalla)(Figure 3). We created a 20 km buffer, an approximate

median range for how far a Raven may fly (Bruggers 1989, Coates et al. 2016, Rösner and Selva 2005, Smith and Murphy 1973, Webb et al. 2009), around observer tracks in order to obtain our three groups. Three analyses were performed for each of the three areas: nest density, nest success, and offending nest status. Diet diversity had sufficient data to run for each CHU, so a pellet analysis was conducted for each of the eight units.

Environmental Variables

In addition to substrate type (natural or anthropogenic), covariates thought to be influential to nest density, nesting success, and offending nest status were used for analyses. These included: surface texture (i.e. a measure of substrate geomorphology ranging from sand to boulders; Nowicki et al. 2019), Desert Tortoise habitat suitability (Nussear et al. 2009), nest density, distances to potential subsidies (e.g. urban areas, agricultural lands, water resources, and landfills), distance to the nearest roads (a potential subsidy due to roadkill and artificial nest strata), distance to the nearest nest and nearest transmission pole, as well as precipitation and temperature (Table 7, Figures 4-6). The surface texture layer is a map of apparent thermal inertia, and relates to the presence of bedrock, boulders, and fine-grain sediments on the surface. This layer covers the entire Mojave Desert at 100-meter resolution (Nowicki et al. 2019).

We chose to use surface texture layer only for natural substrate nests, while the distance to transmission pole layer was only used for anthropogenic substrate nests, because these variables are probably more important/specific to those particular nesting substrate types.

Nest success and offending nest models also included variables that were influential to nesting ecology such as winter precipitation for foraging, and nest density

and nearest neighbor for competition.

Roads were split into three different categories: 1) major/minor arterial and collector roads, 2) local roads, and 3) 'other' roads. Major and minor arterial roadways serve the highest volume of traffic and connect cities and rural areas (i.e. interstates, freeways, main city roads, roads with bus routes). Collectors serve as the connection between local roads to main arterial roads. Local roads are "short distance" roads compared to arterial and collector roadways. These roadways provide direct access to adjacent lands, higher road systems, and low traffic volume (Federal Highway Administration 2013). The term 'other roads' was defined as vehicular trails service driveways/private roads, which are mostly unpaved, and unnamed roads with limited access and in rural areas (U.S. Census Bureau 2017).

Urbanized areas were identified by using data from 2016 National Land Cover Database (NLCD) for Urban Imperviousness at a 30-meter resolution (available on www.mrlc.gov) that had impermeability values thresholded at 20 percent, meaning that grid cells with more than 20 percent of their surface area covered by impermeable surfaces were considered to be developed lands in urban areas (Inman et al. 2013).

Agricultural data were taken from a 1-meter resolution gridded dataset with characteristics that included prime farmland (long-term agricultural production), farmland of statewide importance (similar to prime farmland but with greater slopes or less ability to store soil moisture), and unique farmland (lesser quality soils, usually irrigated but may include orchards or vineyards (California Department of Conservation 2018).

Water availability is critical for survival in the desert and can influence foraging

behavior for desert animals (Kotler et al. 1998). Surface water layers (30-meter resolution) from were taken from Global Surface Water for seasonal and permanent bodies of water (Pekel et al. 2016, available on https://global-surface-water.appspot.com/).

Parameter-elevation Regressions on Independent Effects Model (PRISM) dataset, at 800-meter resolution, was used as the primary source for all climatic data (PRISM Climate Group, 2004, http://www.prism.oregonstate.edu). Temperature and precipitation data were matched to monthly nesting observations to directly attribute their potential influence on nesting success.

All covariates were combined to create a 'global' surface layer for the study area and rescaled with a cubic spline resampling method to a common resolution for analyses of 250-meter using gdalUtils (v2.0.1.14, Greenberg and Mattiuzzi 2018). For all analyses, we created a correlation matrix to test for multicollinearity among covariates and removed covariates if r > 0.7. We conducted model selection by stepwise selection using Akaike's Information Criterion (AIC, Venables and Ripley 2002).

Data Analysis

Nest Density

We used Cox point process models to model densities for both natural and anthropogenic substrate nest locations (Baddeley et al. 2015). A crucial assumption of Poisson point process models is that points (nest localities in this case) are independent of one another. Sampling efforts for Raven nests along transmission lines caused clustering and spatial autocorrelation among observations (Figure 7), which violated this assumption. Cox point process modeling with a Gaussian cluster is a modification of the Poisson process that allows for dependence between points by incorporating a random

effect (Baddeley et al. 2015). We used the function kppm in the *spatstat* package (v1.61, Baddeley et al. 2015) in R to model spatial variation in Raven nest density. The best fitting model was then predicted over a window that buffered surveyed routes for each CHU group at 20 kilometers, corresponding with the distance a breeding Raven may travel (Webb et al. 2012). Our models for each CHU group evaluated the following covariates on nest density: distance to landfills, distances to urban areas, distance to roads (highways, local, other), distance to bodies of water (seasonal, permanent), average breeding season precipitation, average breeding season maximum temperature, and Desert Tortoise habitat suitability (Table 4).

<u>Nest Success</u>

A nest was classified as successful if 'nest fate' was noted as 'successful' or if at least one confirmed hatchling/fledgling observation was noted in the dataset on the last day of observation for any given year.

Nest survival models (e.g. Logistic exposure models, Johnson 1979) are a preferable method for this type of analysis, however there were too few revisits to nest locations during any given year to apply these types of models. Instead, we explored potential relationships between the chosen predictor variables with nest success using General Additive Logistic Regression Modeling with a binomial response distribution (success = 1, failed = 0) and logit link function. Generalized additive models (GAMs) are a generalization of GLMs that allow for non-linear relationships (Wood 2004). We scaled the effects of the covariates by using cubic splines, which forces the derivatives of the covariates to agree to the number of set knots. The parameters in the model were estimated by the package mgcv (v1.8-31, Wood 2004) in R software (v 3.5.3, R Core

Team, 2018), with REML fit and variable selection implemented, which effectively reduces the influence of uninformative variables. The basis dimension parameter, k (knots), was set to 3 for all variables, limiting the maximum allowable degrees of freedom and adjusted as needed, but never exceeding 10. We also set the argument gamma to 1.4, inflating the effect degree of freedom by 1.4 in the GCV score which reduces the tendency for models to overfit (Wood 2004). We evaluated model fit using standard AIC metrics (Burnham and Anderson 2004). Covariates used for nest success models were the same as nest density models with the addition of distance to nearest neighbor nest, nest density, and winter accumulation precipitation (Table 7). Additionally, we included a categorical variable indicating whether a nest was considered an offending nest. This allowed us to determine if an offending nest correlates with a nest being successful.

Nest success time series

Finally, we conducted an analysis of nest success over time using the *emmeans* package (v1.4.5 Russel 2020) to determine how nest success varied among each years. For this analysis, nests were aggregated to create unique nest ID that spanned all years for a given survey area. For example, if a nest location (defined as a nest within 5m of the same location among all years) was visited for year 2013, 2014, and 2015; then there would be three observations of that unique nest ID. Covariates that were significant in the previous nest success models were used for these time series models, and year was also included, with nest ID as a random factor to account for repeated measurements. Time series analyses were only done on anthropogenic substrate nests, because all of the CHU groups shared a positive effect on winter precipitation, which was the only time variant

covariate. Other interactions between year and potential covariates were only available for winter precipitation, as other environmental variables (e.g. breeding season temperature and precipitation) were based on 5-year averages. We tested for differences in nest success among years using Tukey's HSD to perform multiple comparisons while controlling for potentially spurious significance effects. To perform these contrasts, covariates were back-transformed from the logit scale, and significance was based on Tukey-adjusted p values (alpha = 0.05, C.I. = 95%). Back-transformation was necessary because models for nest success were conducted using a logit-function.

Offending Nests

We performed a Generalized Additive Logistic Model with a binomial response distribution (offending nest = 1, non-offending nest =0), and logit link function to determine variables associated with an offending nests versus non-offending nests. We used the same statistical methods we used in the nest success analyses for our offending nest models.

Covariates used for offending nest models were distance to: landfills, urban areas, agriculture, different types of roads and bodies of water; Desert Tortoise habitat suitability, Raven density (from the predicted density models), distance to the nearest neighbor nest on the year the nest was found, winter precipitation of year the nest was found, surface texture (for natural substrate models only), and distance to the nearest transmission pole (for anthropogenic substrate models only) (Table 5). No random factors were included in the models to account for repeated measures, as more than half of the nest locations were only monitored for one year.

Pellet Dataset

The Pellet dataset was inconsistent for some CHUs and years during the Raven
Monitoring and Management project between 2013 and 2018. Not all datasets had
percent content type information or pellet content in general, however, they all did
confirm if there were tortoise remains in the pellet, along with several categories of other
non-tortoise content. We summarized the data by nine different categories describing
pellet content: Tortoise, Vegetation, Trash, Mammal, Herp, Invertebrate, Avian , Animal
(nondescript), and "Other", all of which were calculated as binary variables
(present/absent), for each pellet observation (N = 1571). We did not include pellet
information taken from the DTRNA because only one pellet had pellet contents
described. We used R package *vegan* (v2.5-6, Oksanen et al. 2019) to characterize
species diversity in the Raven pellets by using Simpson diversity index (D2, Shannon and
Weaver 1948, Hill 1973,) which generally has good discrimination among sites (Morris
et al. 2014). Diversity values and data summarized as the percentage of each category per
CHU were analyzed relative to the value of desert tortoise habitat model at each pellet
location averaged for each CHU using a general linear model.

Results

Nest Density -- Natural Nest Substrates

The covariates analyzed in the point process models for nest density differed
among the three CHU groups, however there were some variables with shared
significance among the groups (Table 8). All three groups had significant positive effects
for tortoise habitat suitability and surface texture. This indicted higher nest densities in
areas where surface texture values indicated rougher substrates, such as bedrock, and

areas dominated by boulders and cobbles (Nowicki et al. 2019). In addition, nest densities were higher in areas of higher suitability tortoise habitat. The groups also shared significance for distance to urban areas, however, the East and West CHU areas had positive effects (where nest density was higher further from urban areas), while the south CHU group had a negative effect (where nest density was higher closer to urban areas), likely due to the relative position of urban relative to suitable nesting areas within the areas. Additionally, there were distinct significant variables that were not common among all three groups: a) the West and South CHUs both had negative effects for distance to local roads, b) the West CHUs had a positive effect for precipitation during breeding season, while c) more variables in the South CHUs had effects on nest density such as, distance to seasonal bodies of water, low temperatures during breeding season, and areas that are further from other roads (Table 8).

<u>Nest Density -- Anthropogenic Nest Substrates</u>

There were four variables that influenced anthropogenic substrate nest density. However, effects for the four variables varied among each CHU group. All CHU groups had higher nest densities closer to seasonal bodies of water. Interestingly, the South and East CHUs had positive effects associated with underlying tortoise habitat suitability, while the Western CHUs had a negative effect (Table 9), which is likely due to the habitat suitability that the major power lines traverse through in that area. Nest density in the Western CHUs was associated with closer distances to agriculture and local/neighborhood roads, while the nest density in the South CHU group was associated with further distances from agriculture, and closer distance to 'other' roads. The South and East CHUs had opposite effects (negative and positive, respectfully) for average

maximum temperature during breeding season. Nest density in the Eastern CHUs was significantly associated with a closer distance to landfills.

Nest Success -- Natural Substrate Nests

Natural substrate nest success among the three CHU groups had regionally distinct effects among the predictor variables. The Western CHUs nest success for natural substrate nests was associated with areas of lower tortoise habitat suitability and lower Raven nest density (Table 10, Figure 12). Nest success for the South CHU group was mainly associated with roads and higher winter precipitation levels (Table 10, Figure 16). Success of nests in the East CHU group was associated with lower breeding season temperatures, closer distances to seasonal bodies of water, and higher surface texture (Table 10, Figure 14). Natural nests with offending nest status were less likely to be successful in the South CHU group, and offending status was not a significant influence for the other two groups (Table 12).

Nest Success -- Anthropogenic Substrate Nests

Winter precipitation was a significant effect shared among the three groups relative to anthropogenic nesting success, and had a positive influence in the West CHUs, and peaking at intermediate values in the East and South CHUs (Table 11, Figure 13, Figure 15, Figure 17). Nests in the South CHU group had a positive association with maximum temperature during the nesting season, and a negative effect with distance to landfills, which was also significant for the East CHU group (Table 11, Figure 15). Anthropogenic nest success in the South CHU group was associated with higher Desert Tortoise habitat suitability (peaking at intermediate values), while this was not significant for the other areas (Table 11, Figure 17). Nesting success was negatively associated with

offending nests for the West and East CHU areas, and not a significant factor in the South CHU (Table 12).

Nest Success – Time series

The probability of nest success for the West CHUs significantly differed for year 2013 (probability = 14.5%) and 2016 (probability = 69.1%) (p = 0.0266). The South CHUs had varying probabilities from 2013 to 2015, where the probability of nest success decreased from 67% to 19.9% (p = 0.0019) and then increased the following year to 58.9% (p = 0.0388). For the East CHUs nest success was significantly lower for year 2014 (probability = 24%) and 2017 (69.6%) pair (p = 0.0327). Overall, the probability of nest success between years after 2014 for winter precipitation did not differ significantly (p > 0.05, Figure 18A, 18B, and 18C)

Offending Nests

Offending nests had regionally distinct relationships with covariates. We found that for both natural and anthropogenic nests in the West CHUs, offending nests were associated with positive effects of distances from subsidies, such as roads, urban areas, and agriculture. In addition, there were negative effects associated with distances from permanent bodies of water and high densities of Raven nests (Tables 13 and 14). The South CHUs only had significant influences for natural nests, as the sample size for anthropogenic nests was too low. Natural nests classified as offending in the South CHUs were associated with areas that had lower surface texture values, associated with flatter, less rugged terrain. Desert Tortoise habitat suitability was positively associated with offending status for both natural and anthropogenic subsidies in the East CHU group, but was not significant for the other two areas. Finally, the effects of winter precipitation

were opposite for natural (positive) and anthropogenic (negative) substrate nests in the East CHUs, and not significant for the other two areas (Tables 13 and 14).

Pellet Dataset

Diet diversity indices yielded similar values among all Critical Habitat Units (generally ranging from 4.8 to 6.2) with the exception of Chuckwalla, which had a far lower diversity than the others (2.7, Figure 19). Rankings of the average percentage for each category indicated that 97 percent of the pellet contents contain food items other than tortoise (Table 15), and the top items identified in pellets included invertebrates, mammals, herpitle, and avian contents, each of which was above 10%. Tortoise contents were only prevalent in pellets collected within one of the CHUs (19% - Chemehuevi), however diet diversity for Chemehuevi was similar to most other sites (Table 11, Figure 19). The lower diversity for Chuckwalla was due to a majority of the pellet contents containing invertebrates, with much lower values in the other diet categories (Figure 20). The percentage of pellets with tortoise remains found was not related to the overall tortoise habitat suitability measured at the pellet locations (P = 0.879), even when excluding the Chemehuevi site as a potential outlier.

Discussion

Anthropogenic subsidies are known to have direct effects on predator species, increasing abundance, altering dietary composition, and ultimately influencing life-history (Boarman et al. 2006, Coates et al. 2020, Newsome et al. 2015, Plaza and Lambertucci 2017). Ravens are known to forage in landfills and agriculture for food and to utilize man-made structures for nesting sites (Kristan et al. 2004, Coates et al. 2014,

Coates et al. 2016). We found that several of the anthropogenic resources typically considered subsidies for this species were significantly associated with higher nest density, and nest success throughout the Desert Tortoise Critical Habitat Units in California, however, the specific subsidy effect and type varied regionally. Our findings support previous studies indicating the significance of anthropogenic factors to raven density and nesting success (Engel et al. 1992, Knight and Kawashima 1993). Additionally, we found evidence of seasonal and climatic factors that also appear to influence Raven nest density and nest success.

Winter precipitation across all areas was higher after 2015 (Figure 6), and average breeding season maximum temperatures ranged from 20 ºC to 33 ºC (Figure 5). Resource subsidies are widely distributed throughout the West CHU, and the majority of its area is comprised of higher Desert Tortoise habitat suitability (min = 0.68), and sparse distribution of rougher substrate types compared to the East and South CHUs (Figure 4 and 5). Subsidies in the East and South CHUs were more prevalent along the edges of the buffered boundary, and these areas had higher surface texture values - corresponding with rougher terrain - spread throughout the landscape. Nest densities on natural substrates had a significantly positive relationship with rougher surface textures, and offending nests were generally denser further from subsidies (Table 8).

Previous studies found that Raven abundance was higher in landfills (Restani et. al. 2001, Boarman et. al. 2006), and that Ravens nested disproportionately near food and water subsides, but not near roads (Kristan and Boarman 2007). Although Raven abundance may be higher at landfill sites, in our analyses evidence that landfills were significantly associated with nesting density was only seen for anthropogenic substrate

nests in the East CHUs and natural substrate nests in the South CHUs.

We also found that anthropogenic substrate nests were in higher densities near roads for all CHU groups such as: the Western CHU nests were associated with local/neighborhood roads, the South CHUs with "other" (low volume) roads, and the East CHUs with main roads. Transmission lines were correlated with road networks throughout our study. We hypothesize that this correlation aids Ravens with additional nesting sites where road-killed animals may provide a food source for scavenging that might otherwise be unavailable (Boarman and Heinrich 1999).

Coates et al. (2016) found that Raven occurrence increased 45.8% in areas where livestock were present, and that ravens selected for sites with increasing cropland and urbanization. We found strong evidence for nest selection in areas closer to urbanized areas for all sites and substrates (except for natural nests in the South CHUs); however, higher nest density was only associated with agriculture in anthropogenic substrate nests in the West CHUs where agriculture is more prevalent (Table 9, Figure 4).

Esque et al. (2010) found that predation rates on Desert Tortoises were higher near human population concentrations, and hypothesized that subsided predators (coyotes) were likely the cause of elevated predation rates. In our analysis we found that offending Raven nests were not closely associated with urbanized areas. Instead, access to water and areas with higher winter precipitation were significantly related to offending nests for both natural and anthropogenic substrate nests (Tables 13, and 14). In addition to the relationships in the models not including "offending" nest status, we found negative effects on whether a nest was offending, indicating that these nests tended to be in areas with a suite of conditions that reduced success, and that the addition of tortoises

into their diets did not in fact appear to improve the likelihood of success (Peterson 1994, Patterson et al. 1998, Ostfeld and Keesing 2000, Hernandez et al. 2002, Grubbs and Krausman 2009).

Winter precipitation and access to water were also associated with nest success across all CHU groups, and for anthropogenic nesting substrates. Overall, the probability of nest success was not significantly different between years after 2014. This may be due to varying sampling efforts during the early stages of the nest monitoring study, or due to a threshold effect of rainfall on nest success, where above a certain precipitation threshold it is not a limiting factor.

Management implications and Future Work

To help inform Raven monitoring and management decisions throughout California's Desert Tortoise CHUs, we estimated a critical nesting (anthropogenic and natural) density to be approximately seven Raven nests per km^2, where nest success may increase with densities lower than seven, and the probability of a nest becoming offending increases with increasing densities (Table 11, Table 14). Offending nests were also associated with areas further from roads and urbanized areas. We hypothesize that fewer subsidized resources for nesting areas near a water source may promote hunting behaviors for larger prey items. Kristan et al. (2004) suggest that ravens forage opportunistically on foods available near their nests. Invertebrates and mammals make up the majority of breeding Raven diets in our analyses. We found that high nest density is associated with roads and urbanized areas, areas where food source may be supplemented by road-kill, and human-provided food (Kristan et al. 2004).

Raven nest success is associated with high winter precipitation, therefore,

monitoring and removal/oiling efforts should increase during the following breeding season, especially in areas/years with higher winter rainfall. Additionally, monitoring and management efforts should concentrate in areas where landfills are present and water sources are available rather than just along roads and transmission lines, as these areas were seen to be associated with high nest success. Fencing, and alternative wildlife crossing routes along high volume roads may reduce road kills (Jaeger and Fahrig 2004, Nafus et al. 2013, Polak et al. 2014). Reducing availability of food sources to ravens may reduce nest success and predation pressure on threatened species. Covering of trash in urban areas, landfills, and campsites may also reduce populations of subsidized species (Oro et al. 2013, Pons and Migot 1995). Cities such as Barstow, Victorville, and Yucca Valley/Twentynine Palms, should be closely monitored as they have higher human population densities, and share borders or are within typical raven travel ranges (20km) of a CHU (Figure 11).

Managers balance survey efforts with areas with high surface texture when managing or surveying for natural substrate nests. Also, we found that nest success for natural substrate nests differed between the three groups. Therefore, each regional group should be monitored and managed accordingly. However, a more thorough study should be done in order to determine the regional effects of nest success on natural substrate nests to determine effective management plans, as this dataset was biased toward anthropogenic substrates.

Figures
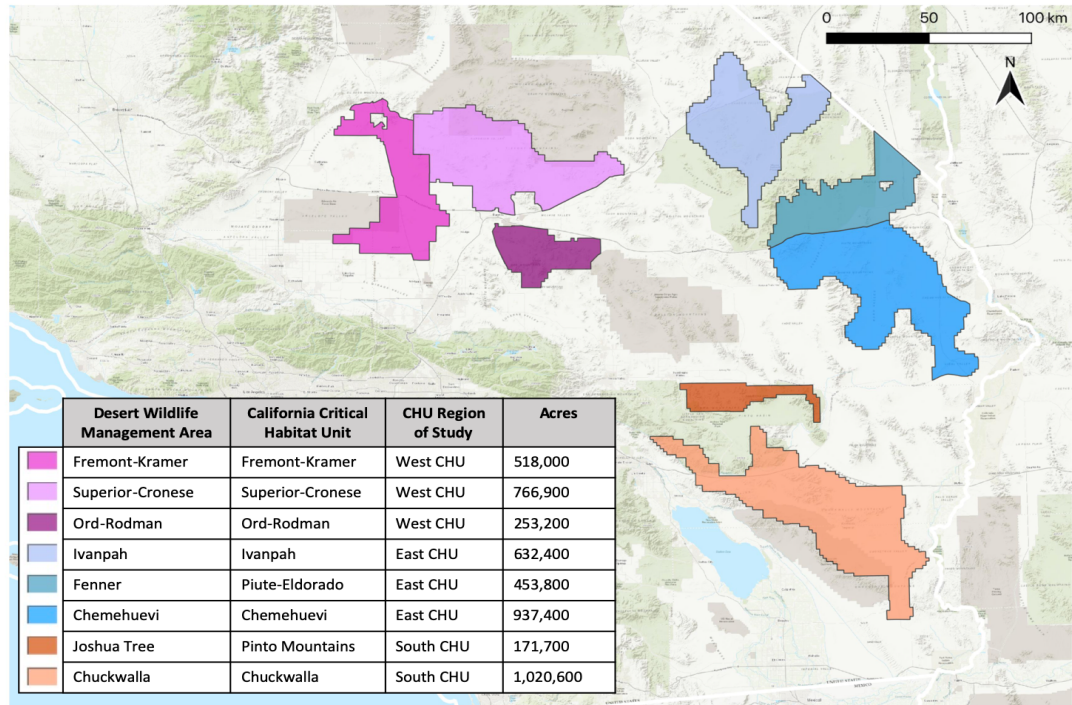
Figure 1. California Desert Tortoise Critical Habitat Units
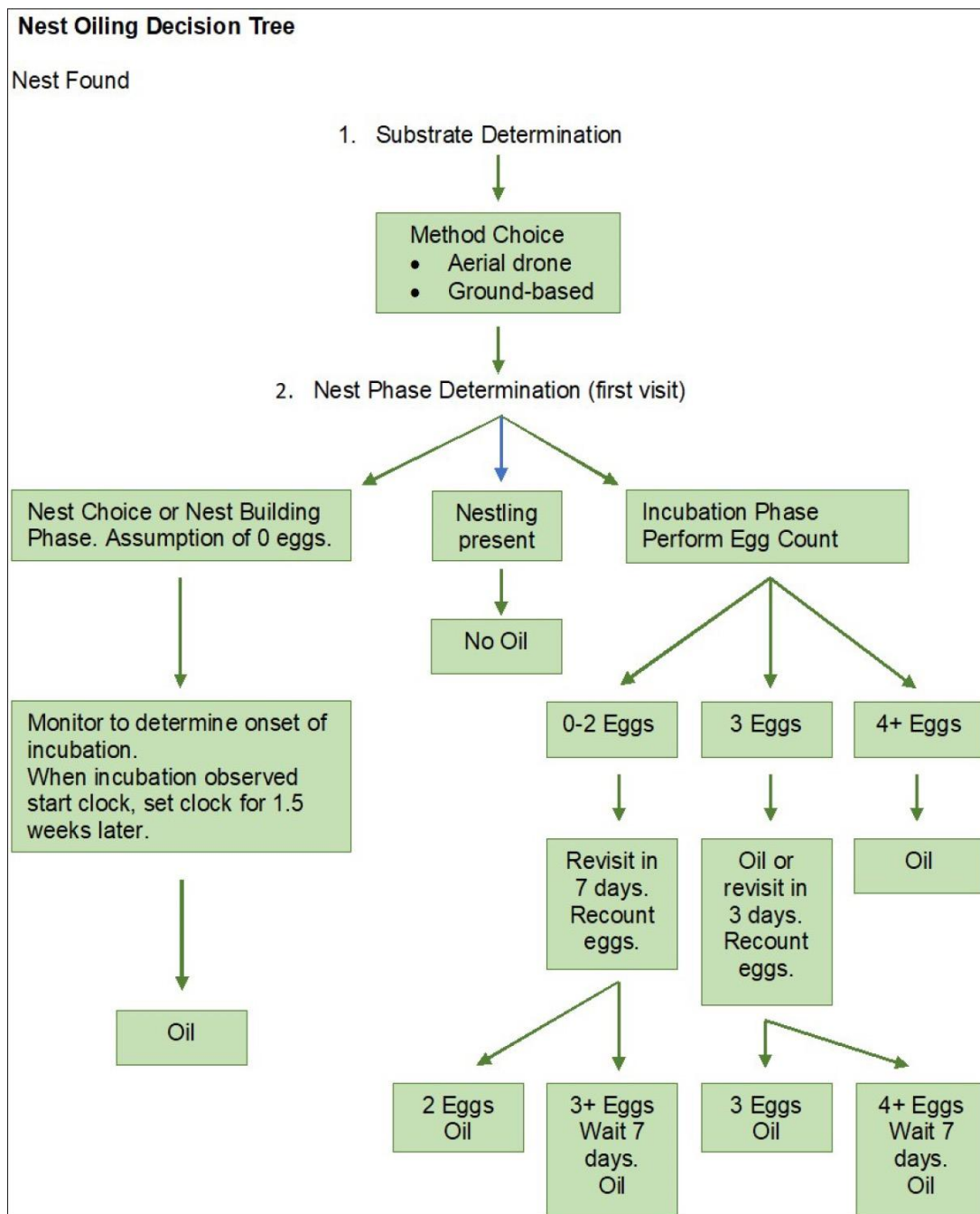
Figure 2. Nest Oiling Decision Tree. (Sundance, Inc. and Hardshell Labs, Inc. 2018)
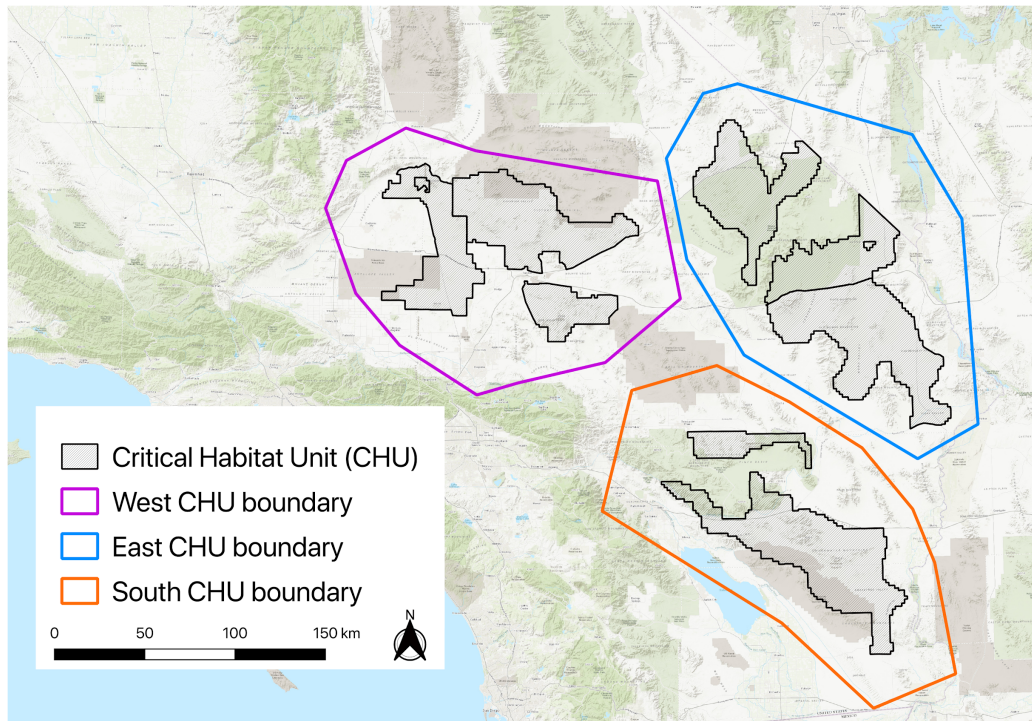
Figure 3. Three Critical Habitat Unit groups (West, South, and East) used for each analysis. The East group contains Ivanpah, Piute-Fenner, and Chemehuevi CHUs. The South group contains Pinto Mountain and Chuckwalla CHUs. The West group contains Superior-Cronese, Fremont-Kramer, and Ord-Rodman CHUs.
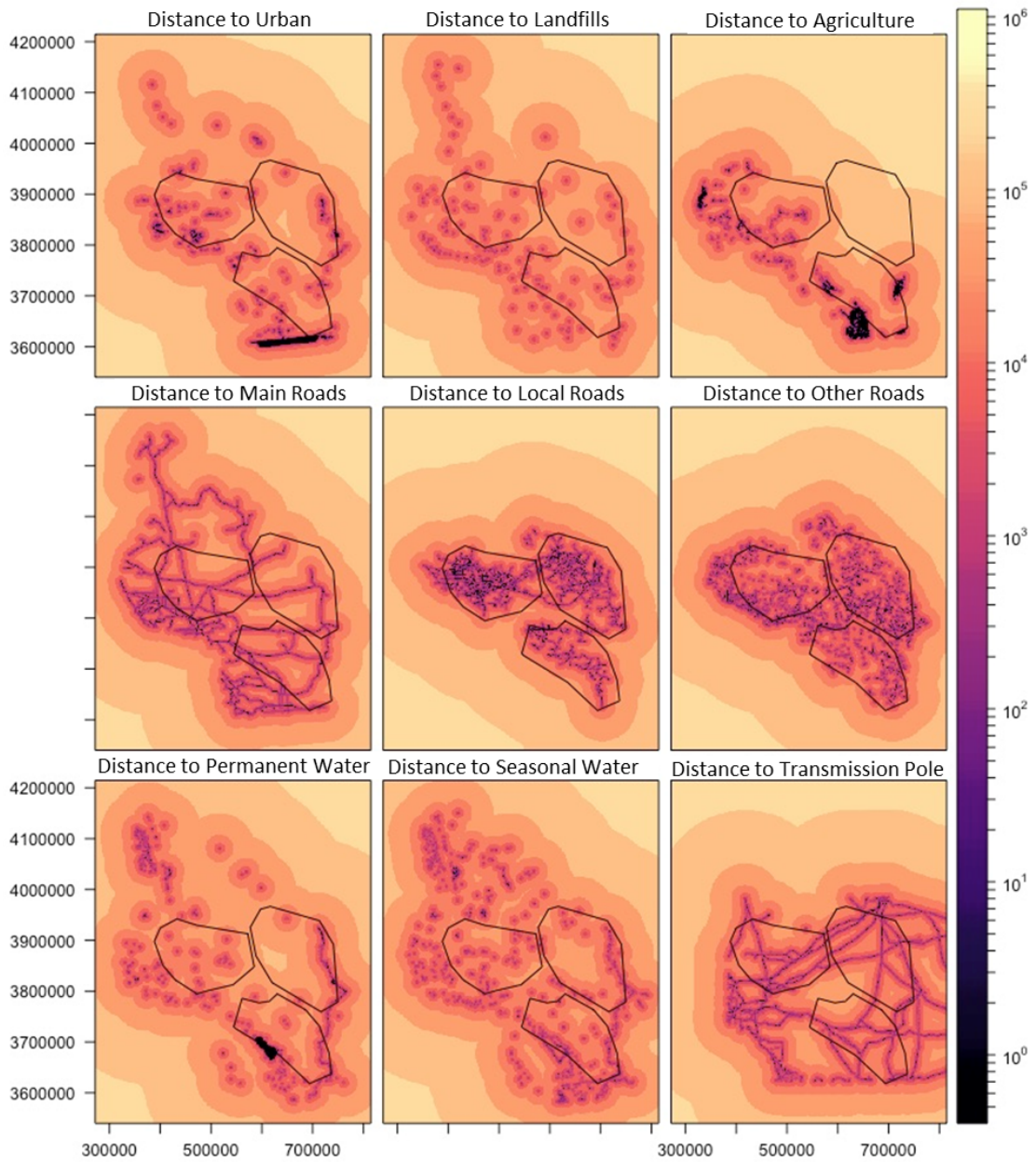
Figure 4. Log-transformed distance covariates used for all models across the three CHU groups. Distance to transmission pole was only used for anthropogenic substrate nest models. Distance to agriculture was not used for east CHU models due to the lack of agriculture in that region.
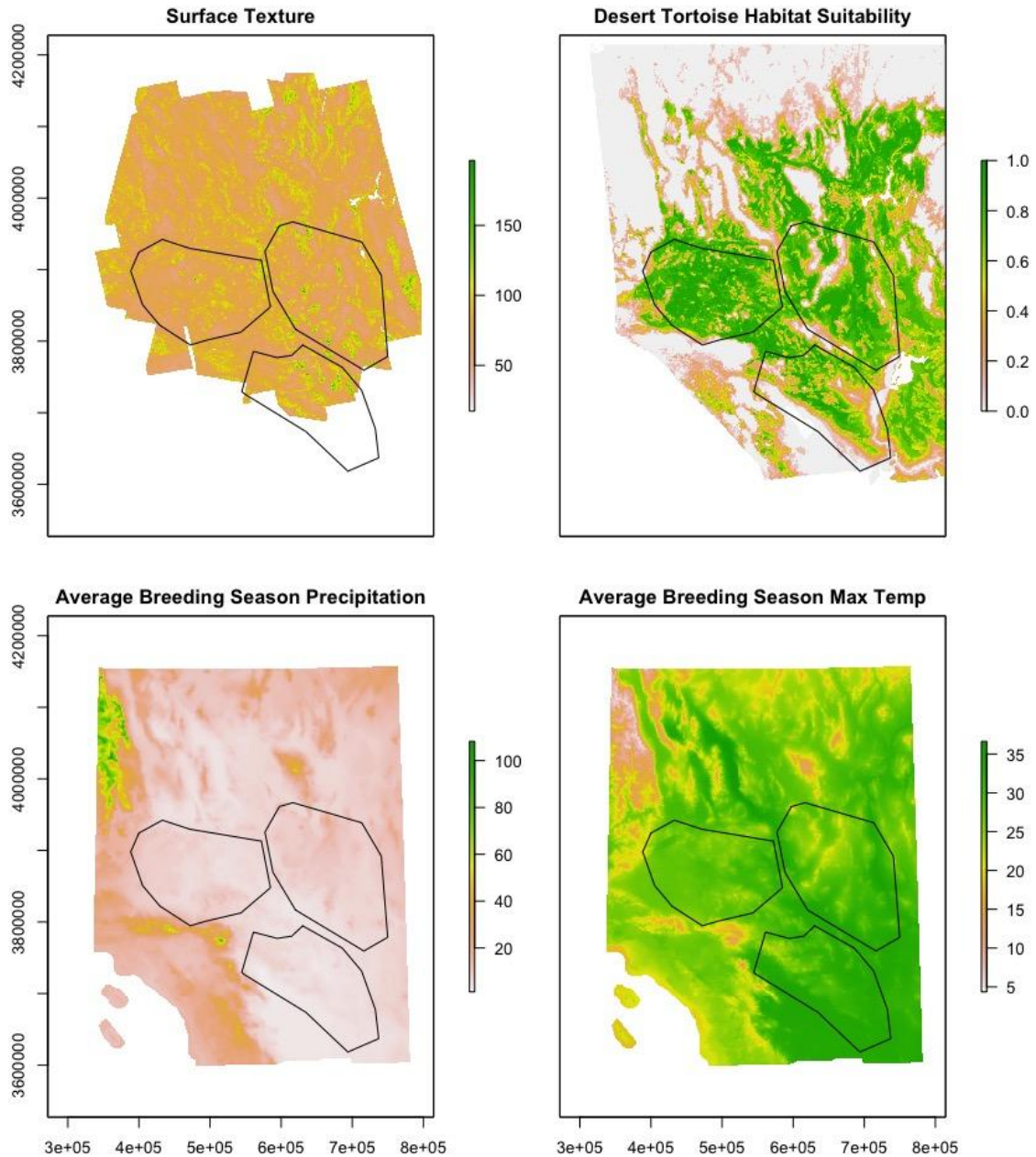
Figure 5. Environmental covariates used for all models across the three CHU groups. Surface texture (geomorphic units) ranges from smooth (low values) to rough (higher values) and used only for natural substrate nest models. Desert Tortoise habitat suitability ranges from low suitability (0) to high suitability (1). Precipitation (millimeters) and maximum temperature (degree Celsius) are averages from years 2012 to 2018 breeding season (March - July).
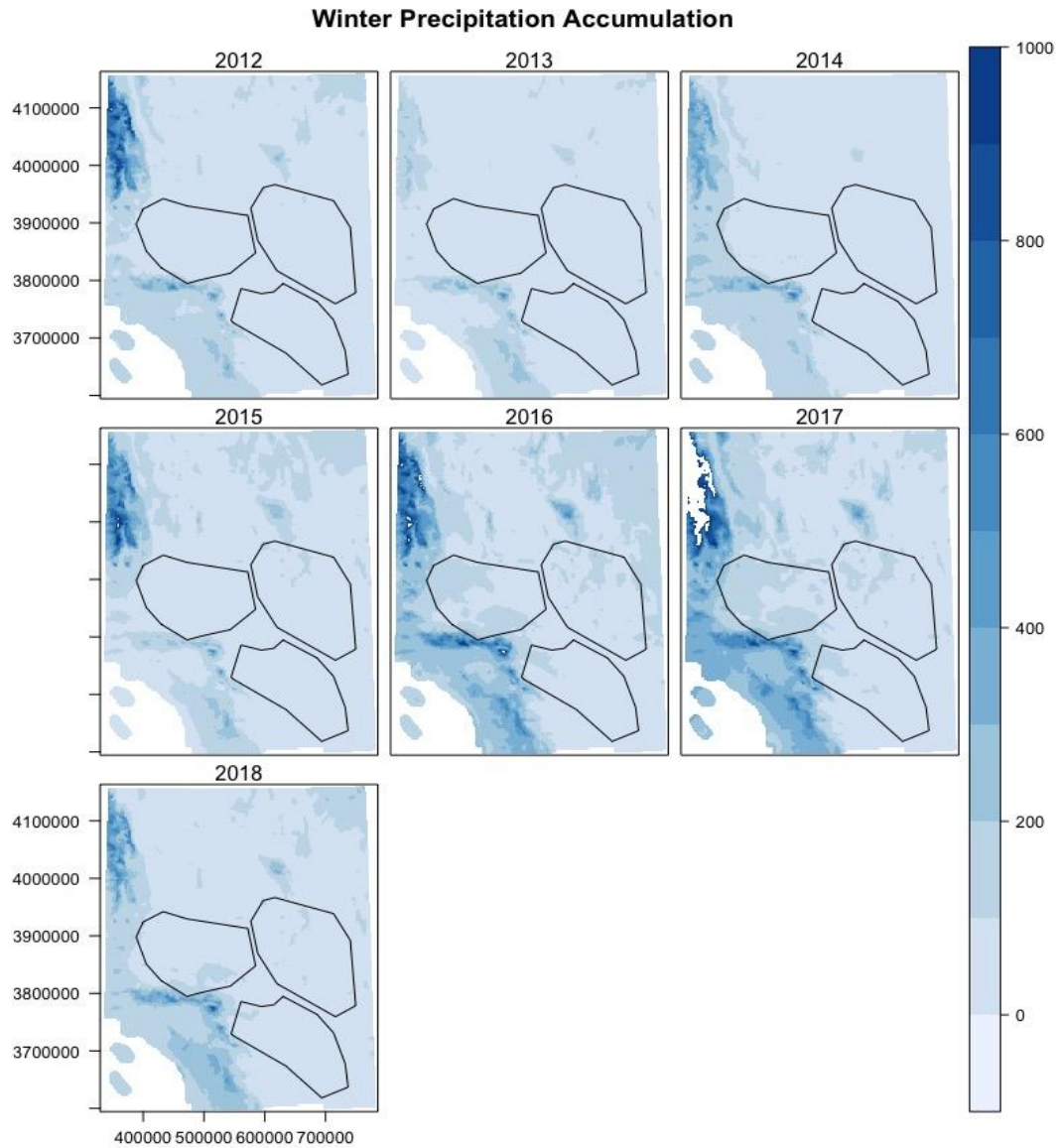
Figure 6. Accumulation of winter precipitation (Nov-Feb) for each sampling year (2013-2018). Winter precipitation (mm) was used for nesting success and offending nest models.
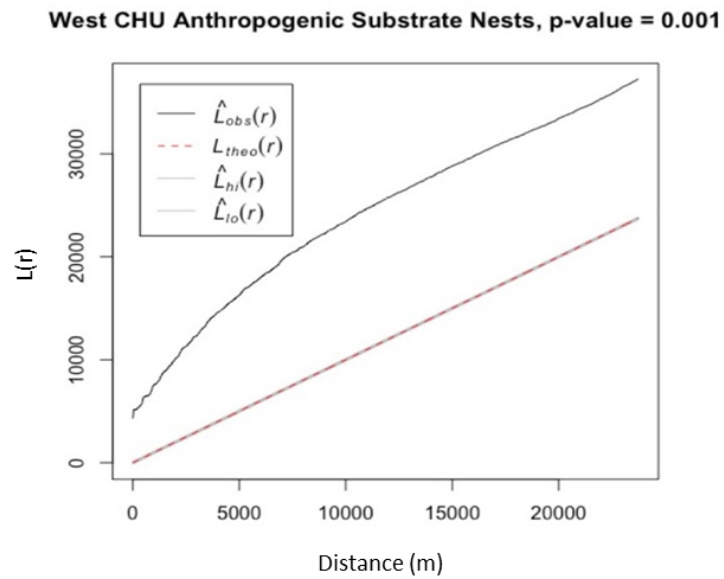
Figure 7. L-function test for clustering in dataset. Empirical L-function (solid lines) and theoretical L-function (dashed lines) for anthropogenic substrate nest in West CHU. This pattern with p-value shows that points are significantly clustered, and was the case for all substrate type and CHU groups.
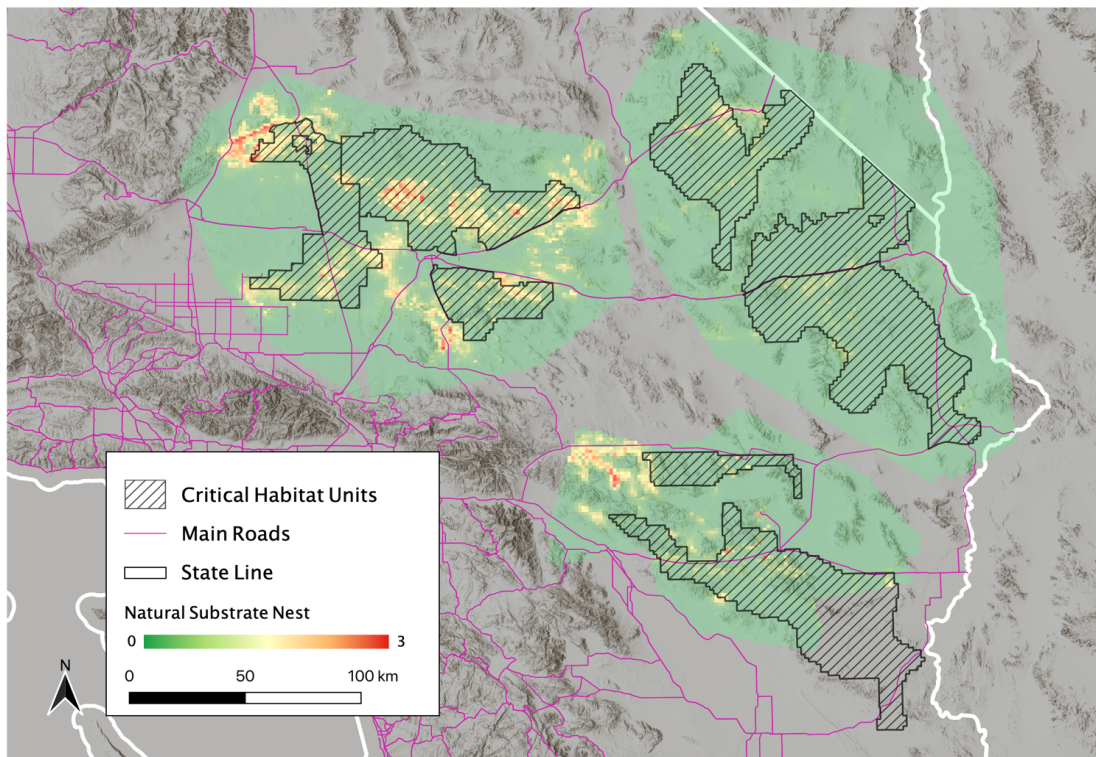
Figure 8. Natural substrate nest density model per kilometer square for the three CHU groups.
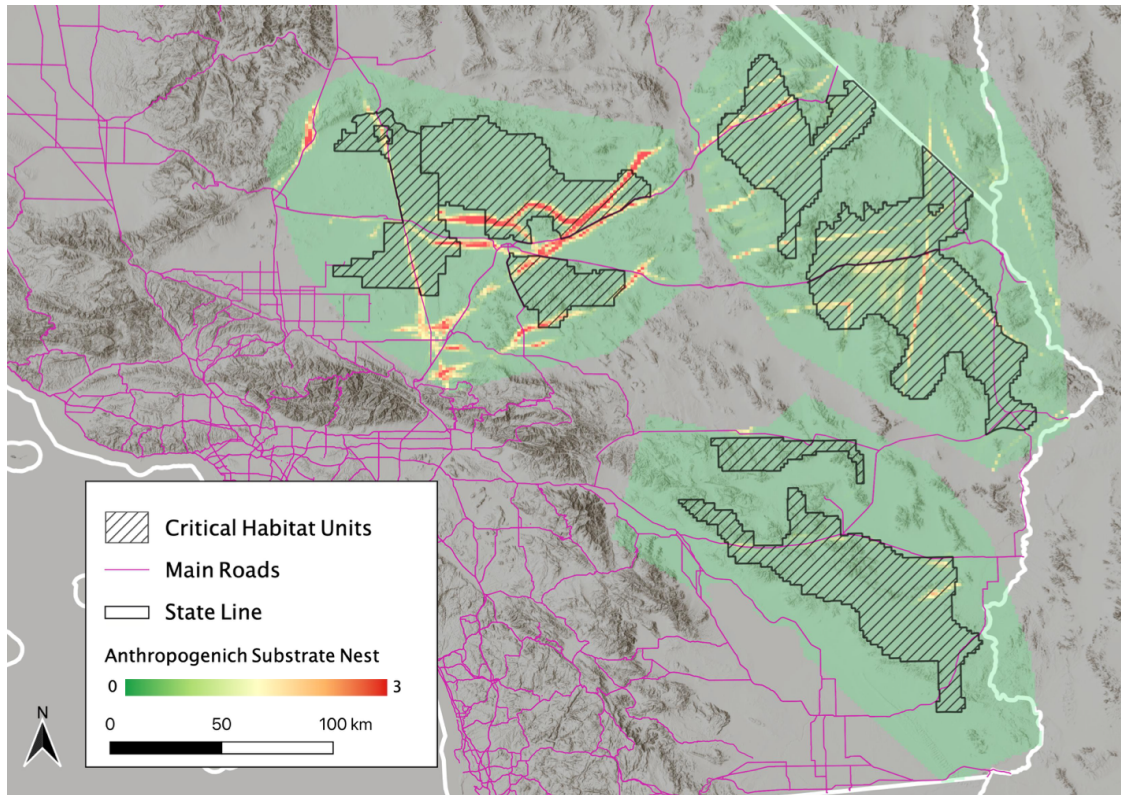
Figure 9. Anthropogenic substrate nest density model per kilometer square for the three CHU groups.
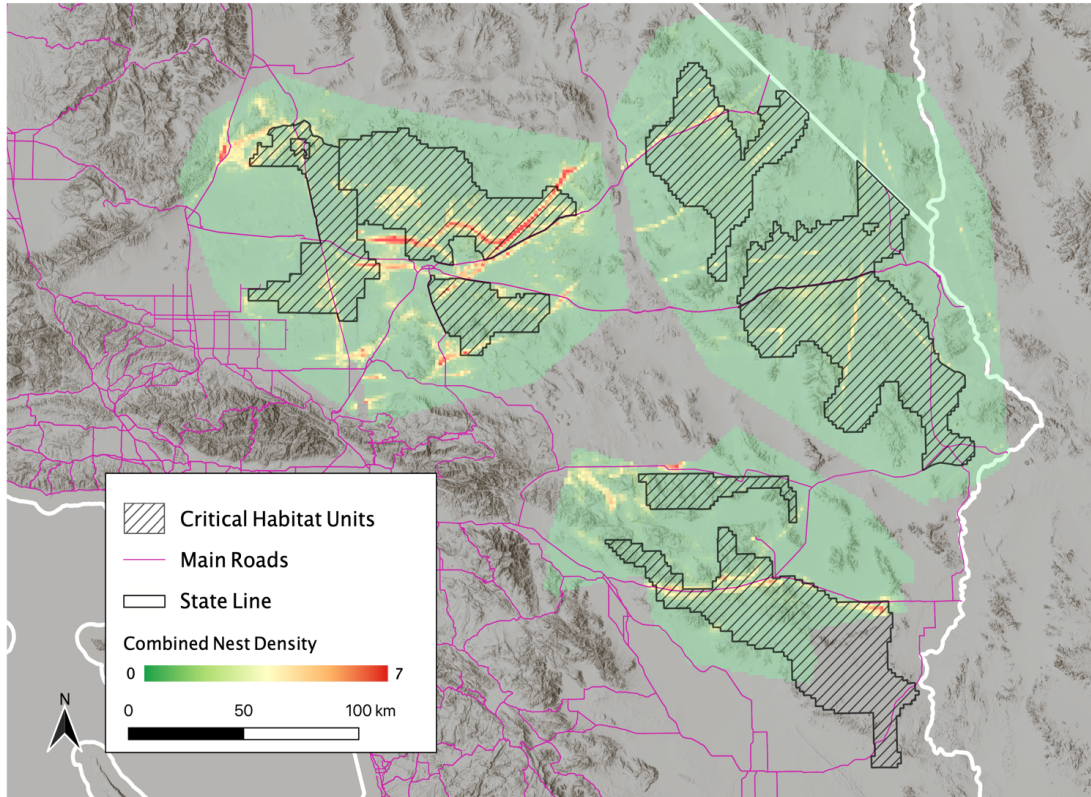
Figure 10. Predicted combined nest density model of areas that may have either natural or anthropogenic substrate nest per kilometer square.
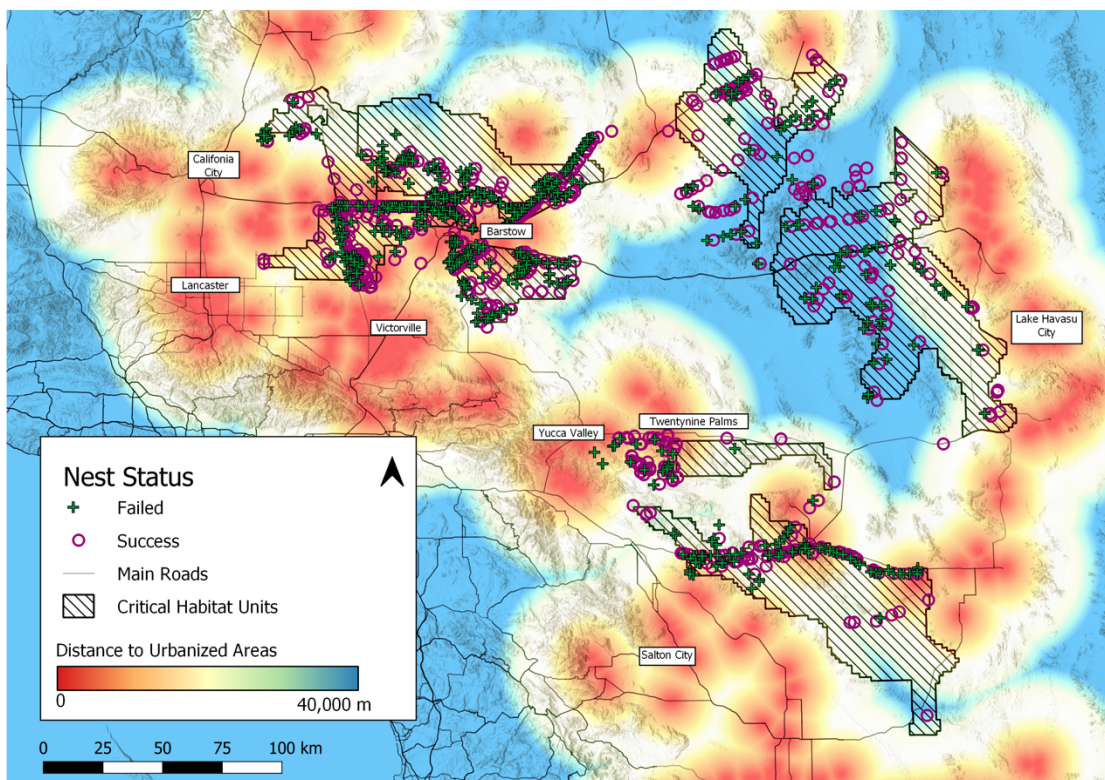
Figure 11. Spatial view of successful (green) and failed (purple) CORA nests in relation to distance to urban.
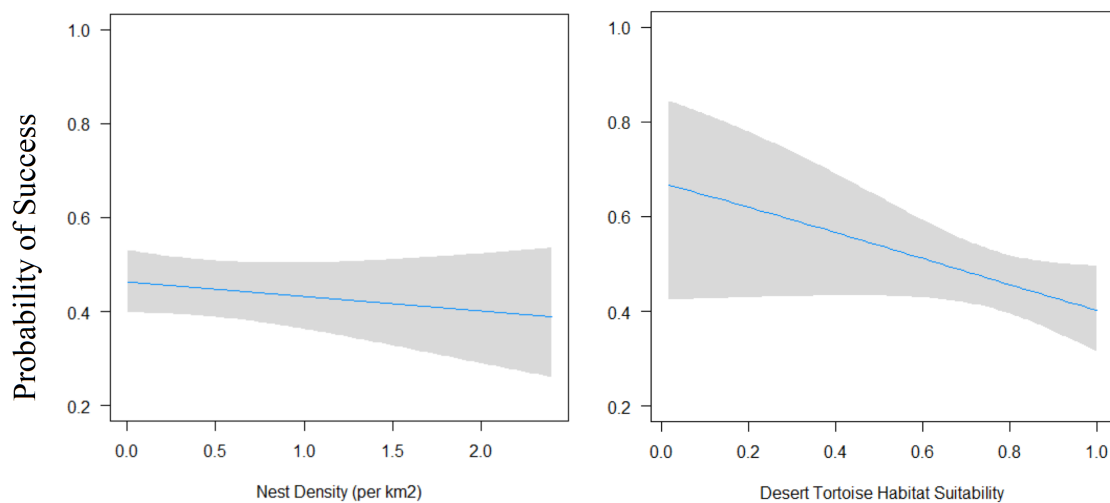
Figure 12. Partial Response Curves for nest density and Desert Tortoise habitat suitability for natural substrate nest success for Western CHU group.

West CHU Anthropogenic Nest Substrate - Nest Success
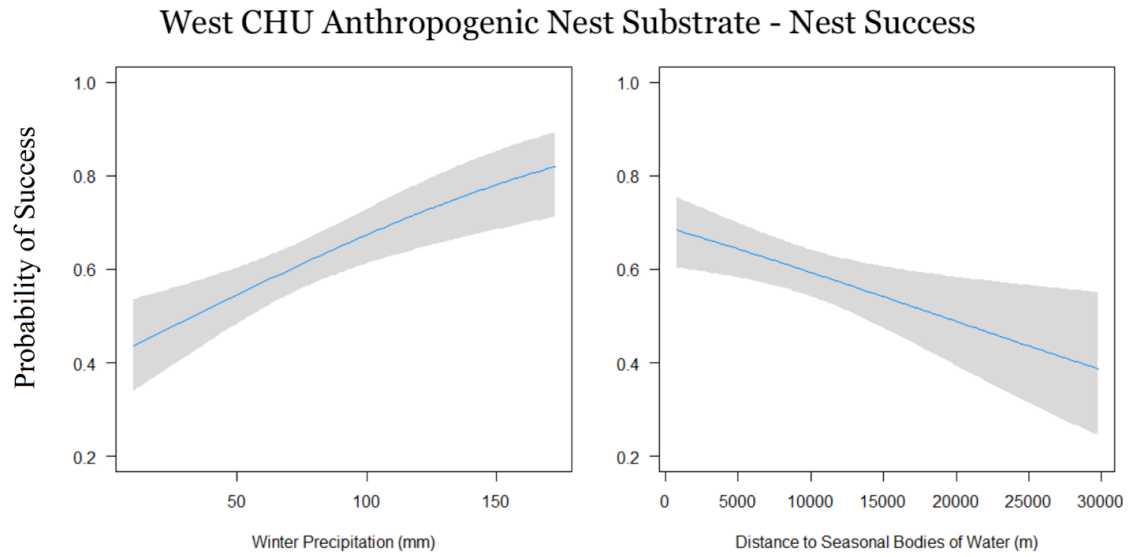
Figure 13. Partial Response Curves for winter precipitation and distance to seasonal bodies of water for anthropogenic substrate nest success for Western CHU group.

East CHU Natural Nest Substrate - Nest Success
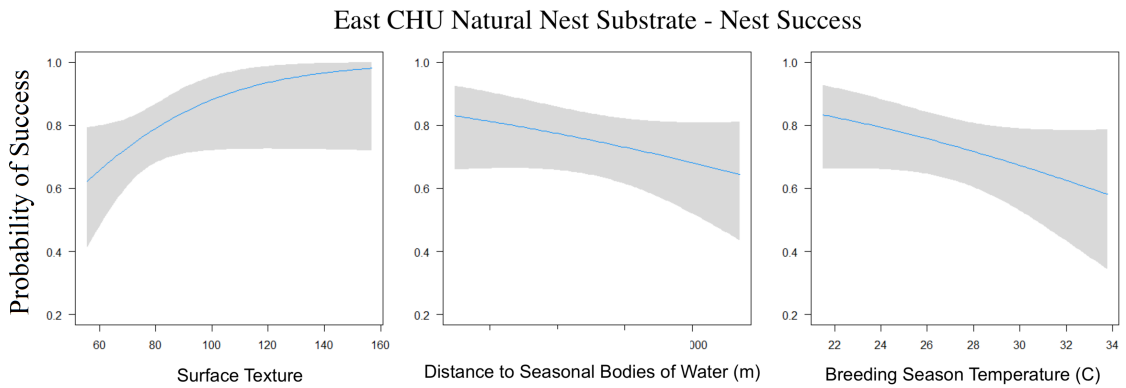
Figure 14. Partial Response Curves for surface texture, distance to bodies of water, and breeding season temperature for natural nest success for Eastern CHU group.

East CHU Anthropogenic Nest Substrate - Nest Success
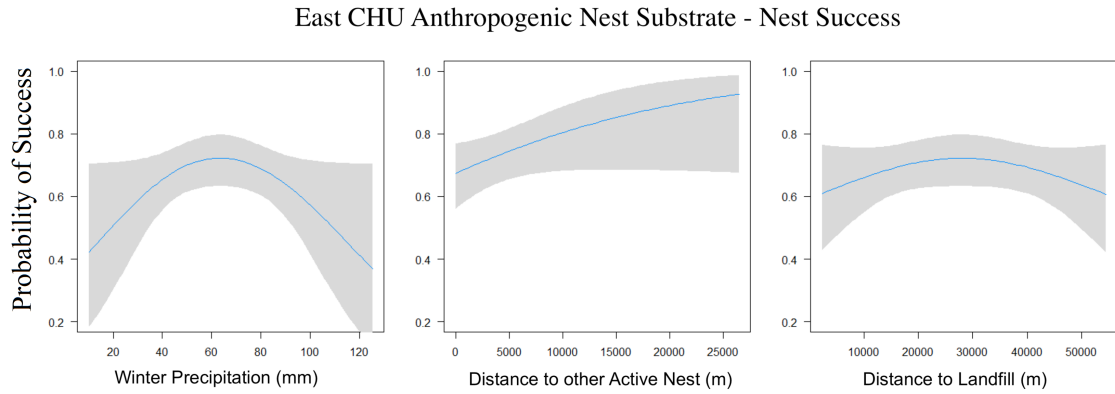
Figure 15. Partial Response Curves for winter precipitation, distance to other active Raven nest, and distance to landfill for anthropogenic nest substrate for Eastern CHU group.

South CHU Natural Nest Substrate - Nest Success
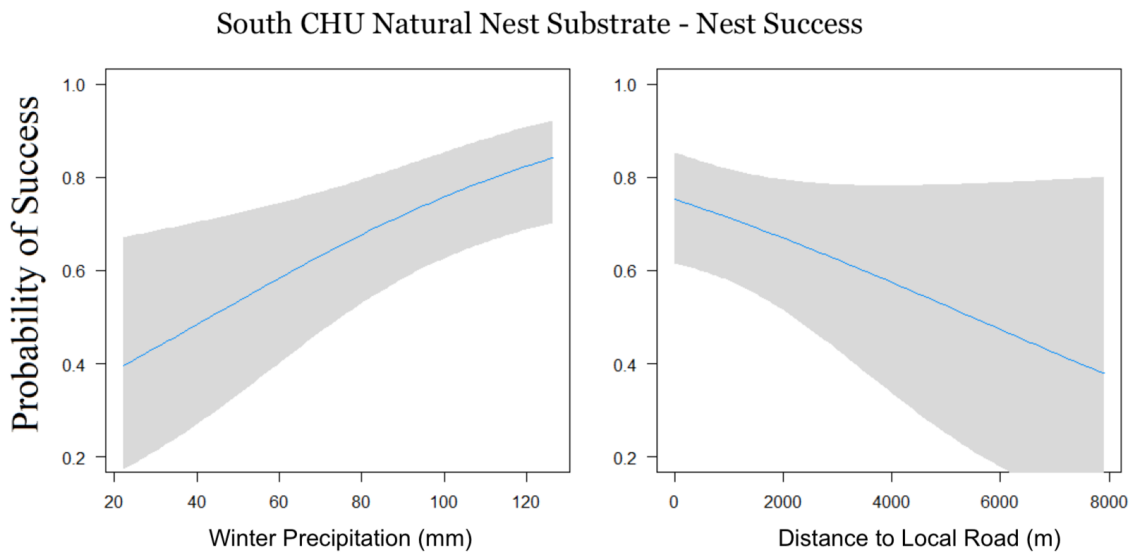
Figure 16. Partial Response Curves for winter precipitation and distance to local roads for natural nest substrate for Southern CHU group.
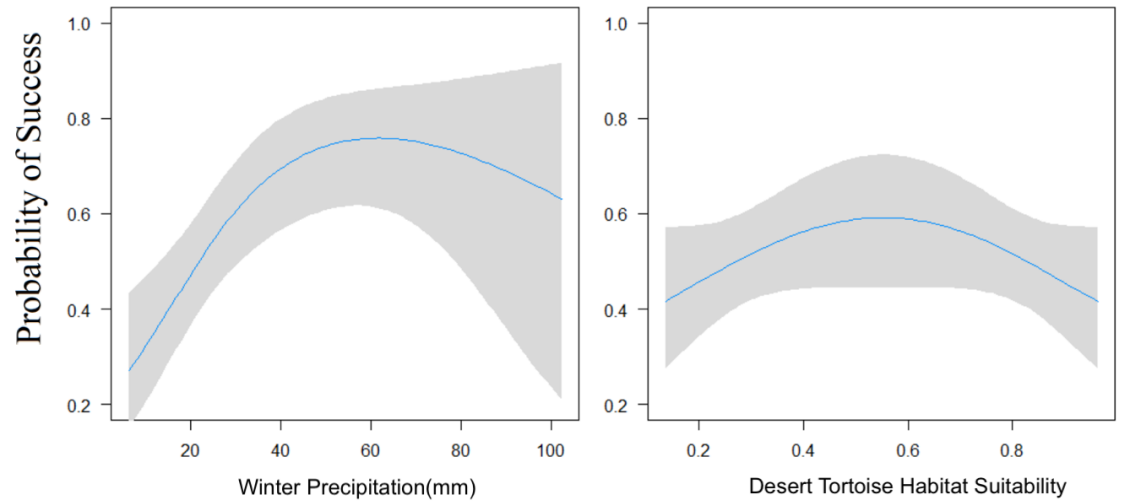
Figure 17. Partial Response Curves for winter precipitation and Desert Tortoise habitat suitability for anthropogenic nest substrate for Southern CHU group.
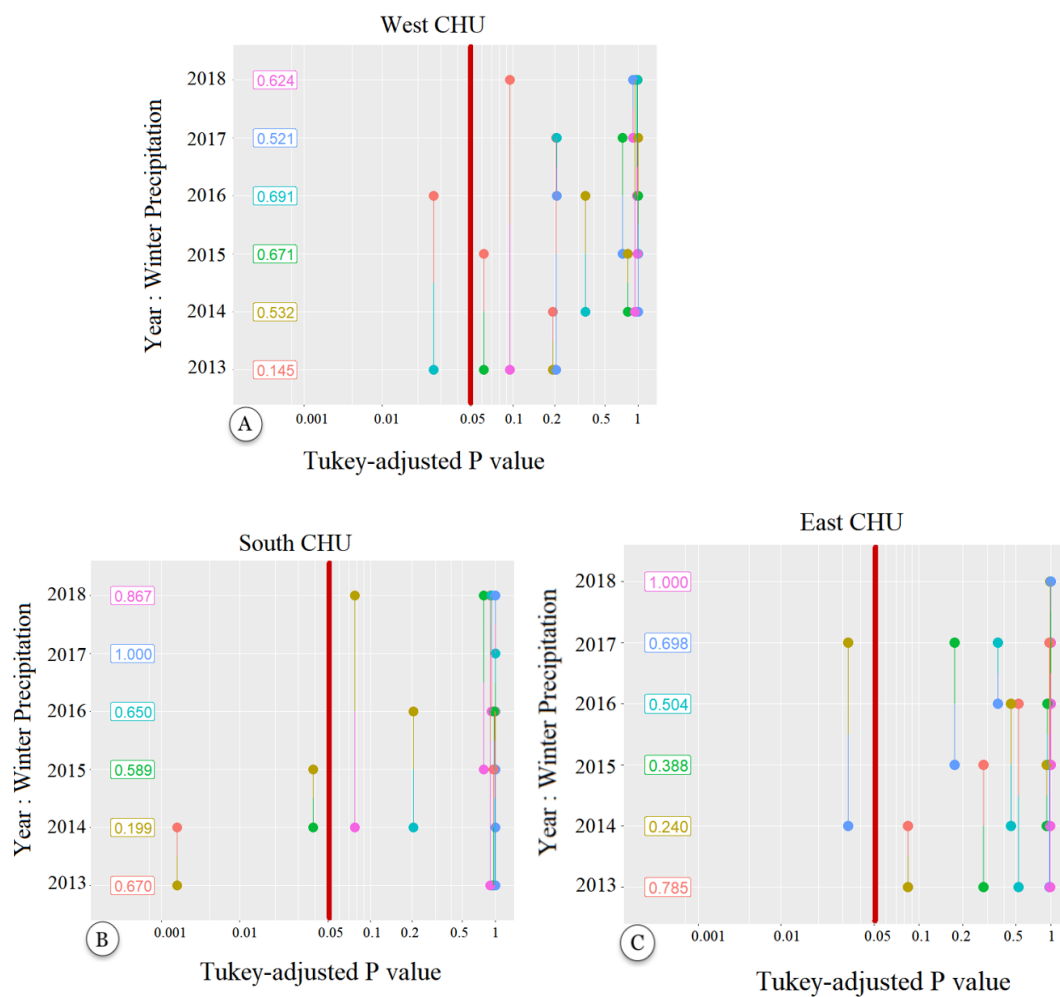
Figure 18A, 13B, 13C. Time series comparison between each winter precipitation year for anthropogenic nests for each CHU group (A = West, B = South, C = East). Estimated probabilities of nest success are shown in color coded boxes next to each year. Segments are color coded for each year pair, and plotted along an adjusted Tukey-adjusted p value on the x-axis (alpha = 0.05, C.I. = 95%). Year-pairs (left of the red solid line, p < 0.05) are years that show significant differences from each other.
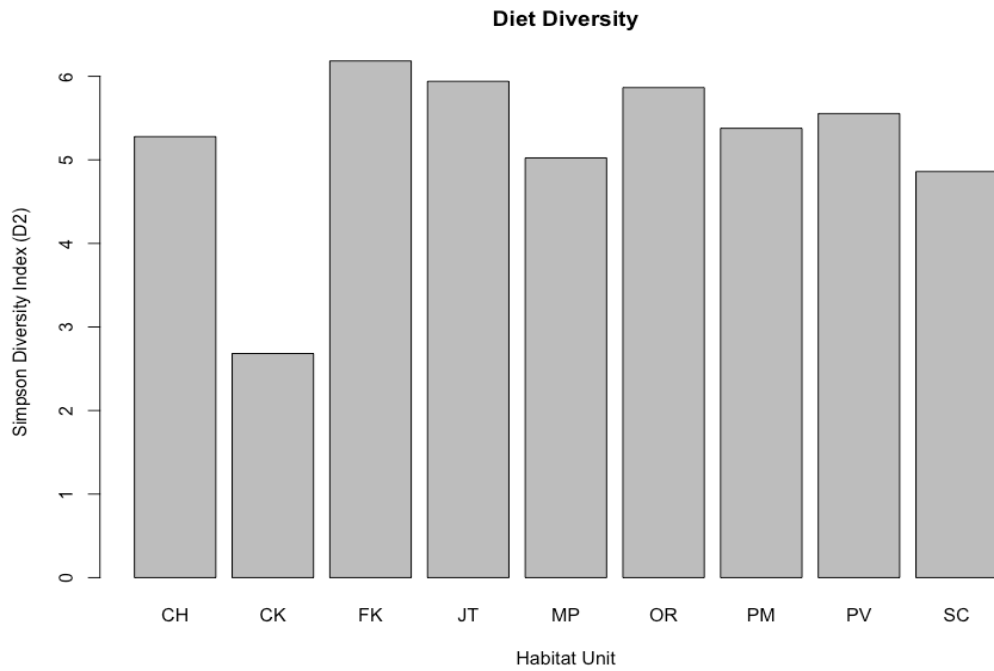
Figure 19. Simpson's diversity index (D2) calculated for pellet content aggregated by Critical Habitat Unit. Diet categories included: Tortoise, Vegetation, Trash, Mammal, Herp, Invertebrate, Avian , Animal (nondescript), and Other. Critical habitat unit abbreviations (left to right) are: Chemehuevi, Chuckwalla, Freemont Kramer, Joshua Tree, Mojave National Preserve, Ord-Rodman, Pinto Mountain, Paiute Valley, and Superior- Cronese.
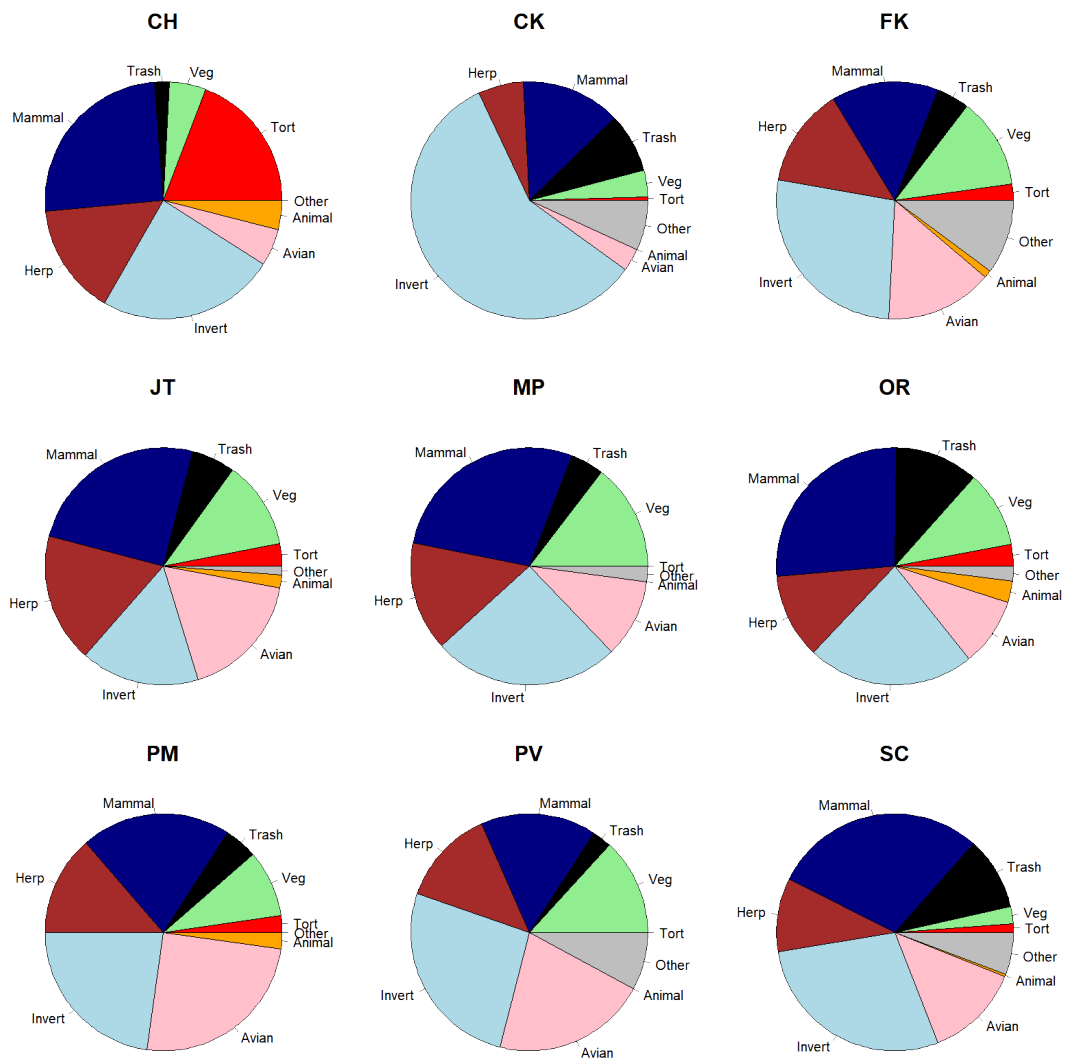
Figure 20. Pie graphs of the relative proportion of the diet categories contained within the pellets among the 9 Critical Habitat Units analyzed. Critical Habitat Unit abbreviations are as given in Figure 19.
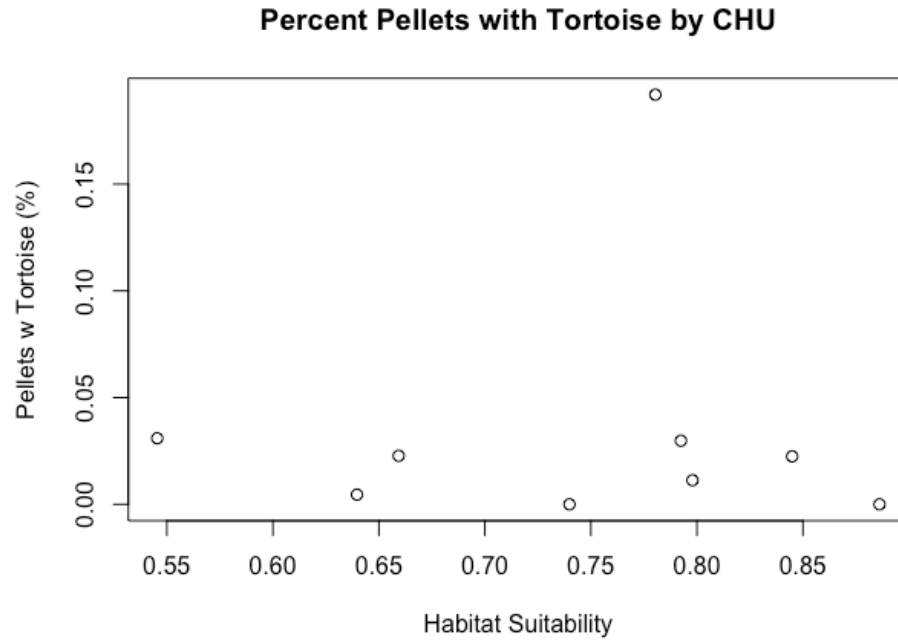
Figure 21. Percent of Raven pellets (by CHU) that had evidence of tortoise carcasses in relation to Desert Tortoise habitat suitability.

Tables

Table 1. List of acronyms used throughout this study

Acronyms	Description
AIC	Akaike Information Criterion
BLM	Bureau of Land Management
CHU	Critical Habitat Units
D2	Simpson's Dominance
DTRNA	Desert Tortoise Research Natural Area
GAM	Generalized Additive Model
GCV	Generalized Cross-Validation
GLM	Generalized Linear Model
KPPM	Cox Point Process Model
LLC	Limited Liability Company
NFWF	National Fish and Wildlife Foundation
NPS	National Park Service
PPM	Point Process Model
REML	Restricted (or residual, or reduced) Maximum Likelihood
RFP	Request for Proposal
USDA APHIS-WS	United States Department of Agriculture Animal and Plant Health Inspection Service – Wildlife Service
USFWS	United States Fish and Wildlife Service

Table 2. Nest monitoring schedule (Corvus 2015) based on the status of the nest site

Status of Site	Monitoring Schedule
Potential substrate or no activity	Monitor once per month
Potential substrate or Ravens observed	Monitor once bi-weekly
Nest or roost present, unconfirmed species	Monitor once per week
Confirmed Raven active nest and tortoise remains not found	Monitor once per week
Confirmed Raven active nest and with tortoise remains found	Monitor once per week and coordinate with Wildlife Services
Confirmed inactive Raven nest	Monitor once per week, conducting inspection if birds are present
Confirmed aggregation with tortoise remains found	Coordinate with Wildlife Services to remove offending Raven(s)

Table 3. Common Raven management and monitoring timeline. Management and monitoring phases for each CHU and NPS (National Park Service) unit from 2013 to 2018 (USFWS unpublished data). Advancement from Phase I to Phase II was promoted by a less than 75% reduction in Raven predator pressure. Where, between 2013 and 2018, Raven predator pressure was measured as the percent of active nests associated with at least one desert tortoise carcass.

CHU and NPS units	2013	2014	2015	2016	2017	2018
Superior-Cronese CHU/Ft. Irwin Conservation Area	Phase 1				Phase 2	
Chemehuevi CHU		Phase 1			Phase 2	
Chuckwalla CHU **	Phase 1				Phase 2	
DTRNA	Phase 1					includes Fremont-Kramer
Mojave NP/Ivanpah CHU/Fenner CHU				Phase 1		
Joshua Tree NP/Pinto Mountains CHU				Phase 1		Phase 2
Ord-Rodman CHU				Phase 1		Phase 2
Fremont-Kramer CHU (includes EAFB and DTRNA)					Phase 1	

**Chuckwalla CHU moved to Phase 2 in 2017 but no management actions were selected due to the low number of offending Ravens; it was deemed cost inefficient for the area
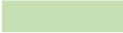
No monitoring, removal, or management efforts

Monitoring action taken

Raven nest mapping as well as monitoring, Raven egg oiling, Mojave desert tortoise carcass surveys at 10% of oiled nests and all nests that did not receive oil, subsidy mapping as well as removal (when applicable), and offending raven removal.

Table 4. Summary table for the Raven Monitoring and Management dataset. The summary includes each CHU and NPS unit for each year the area was surveyed. Nests visited = any nest was observed, which may include more than just CORA nests or even inactive nests. Active CORA Nests = Observed nests that were considered occupied by Ravens and considered to be active. Only ever active nests were used for analysis. Active Anthropogenic substrate nest = nests from the Active CORA nests that was anthropogenic substrate. Active Natural substrate nest = nests from the Active CORA nests that was natural substrate. Active CORA Nest Success = nests from the Active CORA nests that was considered successful

CHU	Year	Nests Visited	Active CORA Nests	Active CORA Anthropogenic Substrate Nest	Active CORA Natural Substrate Nest	Active CORA Nest Success
Chemehuevi	2014	186	22	18	4	9
	2015	236	38	23	15	14
	2016	267	19	12	7	10
	2017	82	26	15	11	26
	2018	130	5	0	5	0
Chuckwalla	2013	240	72	58	14	41
	2014	133	32	32	0	6
	2015	317	38	32	6	20
DTRNA	2013	35	5	0	5	1
Fremont-Kramer	2017	177	141	71	70	76
	2018	268	27	20	7	27
Ivanpah Valley	2013	31	25	25	0	20
Joshua Tree	2016	94	37	12	25	25
	2017	54	35	5	30	31
	2018	159	39	5	34	30
Mojave NP	2016	268	45	37	8	22
	2017	484	70	36	34	49
	2018	423	32	24	8	32
Ord Rodman	2014	2	2	2	0	2
	2016	140	68	39	29	31

CHU	Year	Nests Visited	Active CORA Nests	Active CORA Anthropogenic Substrate Nest	Active CORA Natural Substrate Nest	Active CORA Nest Success
	2017	118	70	34	36	56
	2018	239	55	24	31	11
Pinto Mountains	2018	11	4	1	3	2
Piute-Fenner	2016	46	6	5	1	5
	2017	30	5	4	1	2
Superior-Cronese	2013	96	55	53	2	8
	2014	232	117	88	29	65
	2015	318	118	84	34	70
	2016	182	66	44	22	59
	2017	209	153	91	62	62
	2018	22	22	0	22	3
Total		**5229**	**1449**	**894**	**555**	**815**

Table 5. Summary table for Common Raven offending nests that were considered active. The summary includes each CHU and NPS unit for each year the area was surveyed. Active CORA Offending Nest = nests from the Active CORA nests (from Table 4) that was considered offending. Active CORA Offending Nest Success = the number of nests that were offending and became successful.

CHU	Year	Active CORA Nests	Active CORA Offending Nest	% of Active CORA nests that were Offending	Removal/ WS action Instances	Active CORA Nests Oiled	Active CORA Offending Nest Success
Chemehuevi	2014	22	14	63.6%	7	0	7
	2015	38	8	21.1%	11	0	3
	2016	19	7	36.8%	10	0	6
	2017	26	0	0%	28	0	0
	2018	5	0	0%	0	5	0
Chuckwalla	2013	72	4	5.56%	1	0	2
	2014	32	0	0%	0	0	0
	2015	38	0	0%	0	0	0
DTRNA	2013	5	2	40%	0	0	2
Fremont-Kramer	2017	141	24	17%	14	0	18
	2018	27	2	7.4%	0	0	2
Ivanpah Valley	2013	25	3	12%	0	0	0
Joshua Tree	2016	37	8	21.6%	19	0	6
	2017	35	2	5.7%	4	0	1
	2018	39	5	12.8%	2	0	4
Mojave NP	2016	45	4	8.9%	0	0	0
	2017	70	1	1.4%	42	0	0
	2018	32	1	3.1%	0	0	1
Ord Rodman	2014	2	0	0%	0	0	0
	2016	68	9	13.2%	0	0	1
	2017	70	10	14.3%	11	0	6
	2018	55	6	10.9%	11	0	1
Pinto Mountains	2018	4	0	0%	0	0	0
Piute-Fenner	2016	6	0	0%	0	0	0
	2017	5	0	0%	12	0	0

CHU	Year	Active CORA Nests	Active CORA Offending Nest	% of Active CORA nests that were Offending	Removal/ WS action Instances	Active CORA Nests Oiled	Active CORA Offending Nest Success
Superior-Cronese	2013	55	6	10.9%	0	0	0
	2014	117	19	16.2%	9	0	8
	2015	118	19	16.1%	0	0	9
	2016	66	5	7.6%	8	0	4
	2017	153	18	11.8%	10	29	6
	2018	22	0	0%	0	18	0
Total		**1449**	**177**	**Average = 11.6%**	**199**	**52**	**87**

Table 6. Summary table for wildlife service actions, removals, and oiling attempts on Common Raven nests that were considered active. The summary includes each CHU and NPS unit for each year the area was surveyed. Removal/WS action instances = any time that WS action was taken place, either it be by removal or some other WS method. Active CORA Nests oiled = nests from the Active CORA nests that were oiled. Active CORA Oiled Nest Success = the number of nests that were oil and became successful.

CHU	Year	Removal/ WS action Instances	Removal/ WS action Nest Success	Active CORA Nests Oiled	Active CORA Oiled Nest Success
Chemehuevi	2014	7	1	0	0
	2015	11	0	0	0
	2016	10	0	0	0
	2017	28	0	0	0
	2018	0	0	5	0
Chuckwalla	2013	1	1	0	0
	2014	0	0	0	0
	2015	0	0	0	0
DTRNA	2013	0	0	0	0
Fremont-Kramer	2017	14	10	0	0
	2018	0	0	0	0
Ivanpah Valley	2013	0	0	0	0
Joshua Tree	2016	19	4	0	0
	2017	4	2	0	0
	2018	2	1	0	0
Mojave NP	2016	0	0	0	0
	2017	42	0	0	0
	2018	0	0	0	0
Ord Rodman	2014	0	0	0	0
	2016	0	0	0	0
	2017	11	3	0	0
	2018	11	0	0	0
Pinto Mountains	2018	0	0	0	0

CHU	Year	Removal/ WS action Instances	Removal/ WS action Nest Success	Active CORA Nests Oiled	Active CORA Oiled Nest Success
Piute-Fenner	2016	0	0	0	0
	2017	12	0	0	0
Superior-Cronese	2013	0	0	0	0
	2014	9	1	0	0
	2015	0	0	0	0
	2016	8	0	0	0
	2017	10	2	29	0
	2018	0	0	18	0
Total		**199**	**25**	**52**	**0**

Table 7. Covariates used in full models for analyses of natural and anthropogenic nest density, nest success and offending nest models.

Covariates	Models			
	Natural Substrate Nest Density	Anthropogenic Substrate Nest Density	Natural Substrate Nest Success and Offending Nest	Anthropogenic Substrate Nest Success and Offending Nest
Distance to Landfill	X	X	X	X
Distance to Urban (>20%)	X	X	X	X
Distance to Main Roads	X	X	X	X
Distance to Local/Neighborhood Roads	X	X	X	X
Distance to other roads	X	X	X	X
Distance to seasonal bodies of water	X	X	X	X
Distance to permanent bodies of water	X	X	X	X
Distance to agriculture	X	X	X	X
Average breeding season precipitation	X	X	X	X
Average breeding season maximum temperature	X	X	X	X
Desert Tortoise habitat suitability	X	X	X	X
Surface Texture	X		X	
Distance to Transmission Pole		X		X
Nearest Neighbor Nest			X	X
Nest Density			X	X
Winter Accumulation Precipitation			X	X

Table 8. Significant drivers for natural substrate nest density across the three CHU groups. Z values were used to determine the significance of density drivers.

Natural Substrate Nest Density									
	West CHU			South CHU			East CHU		
Covariates	Estimate	Ztest	Zval	Estimate	Ztest	Zval	Estimate	Ztest	Zval
Distance to Urban (>20%)	0.88	***	15.69	-1.17	***	-10.05	0.47	***	4.40
Desert Tortoise habitat suitability	2.78	***	9.16	0.24	*	2.08	1.87	***	7.67
Surface Texture	0.39	***	14.39	0.59	***	7.85	0.41	***	7.24
Distance to Local/Neighborhood Roads	-0.75	***	-3.54	-2.15	*	-2.35			
Average breeding season precipitation	3.26	***	14.37						
Distance to Landfill				0.86	***	6.01	-0.66	***	-7.82
Distance to seasonal bodies of water				-0.46	***	-4.51			
Maximum temperature during breeding season				-0.70	***	-5.54			
Distance to other roads				0.52	***	6.49			

Grayed out boxes = Non significant covariates   Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table 9. Significant covariates for anthropogenic substrate nest density across the three CHU groups. Z values were used to determine significance.

Anthropogenic Substrate Nest Density									
	West CHU			South CHU			East CHU		
Covariates	Estimate	Ztest	Zval	Estimate	Ztest	Zval	Estimate	Ztest	Zval
Distance to Urban (>20%)	1.19	***	14.19	-3.27	***	-6.89	0.88	***	9.63
Distance to seasonal bodies of water	-1.00	***	-6.99	-0.47	**	-2.71	-0.36	***	-4.67
Distance to permanent bodies of water	-0.25	***	-4.57	1.77	***	8.89	0.35	***	7.10
Desert Tortoise habitat suitability	-0.11	**	-2.58	1.84	***	9.25	0.53	***	5.05
Distance to agriculture	-1.28	***	-15.51	0.56	*	1.98			
Maximum temperature during breeding season				-1.17	*	-2.06	0.66	***	6.14
Distance to Transmission Pole				-1.68	***	-12.2	-7219.62	***	-3.37
Distance to Main Roads	1.62	*	2.13				-0.38	***	-5.01
Distance to Local/Neighborhood Roads	-1.91	***	-4.84						
Distance to other roads				-0.51	***	-3.56			
Distance to Landfill							-1.21	***	-15.03
Grayed out boxes: Non significant covariates Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1									

Table 10. Significant covariates for natural substrate nest success across the three CHU groups.

| Covariates | Natural Substrate Nest Success Drivers | | | | | | | | | | | |
| | West CHU | | | | South CHU | | | | East CHU | | | |
	EDF	Sign	P	Sig.	EDF	Sign	P	Sig.	EDF	Sign	P	Sig.
Desert Tortoise habitat suitability	0.690	-	0.035	*								
Nest Density	0.491	-	0.097	.								
Distance to Main Roads					0.720	+	0.013	*				
Distance to Local/Neighborhood Roads					0.606	-	0.041	*				
Winter Accumulation Precipitation					0.814	+	0.001	**				
Distance to seasonal bodies of water									0.603	-	0.077	.
Average breeding season maximum temperature									0.641	-	0.052	.
Surface Texture									0.762	+	0.028	*

Grayed out boxes = Non significant covariates   Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table 11. Significant covariates for anthropogenic substrate nest success across the three CHU groups.

| Covariates | Anthropogenic Substrate Nest Success Drivers | | | | | | | | | | | |
| | West CHU | | | | South CHU | | | | East CHU | | | |
	EDF	Sign	P	Sig.	EDF	Sign	P	Sig.	EDF	Sign	P	Sig.
Winter Accumulation Precipitation	0.886	+	2.17E-05	***	1.524	+	8.24E-05	***	0.580	+	0.0385	*
Distance to seasonal bodies of water	0.792	-	0.002	**	0.231	-	0.099	.				
Distance to Landfill	0.306	-	0.094	.					0.343	-	0.0874	.
Average breeding season maximum temperature	0.500	+	0.044	*								
Desert Tortoise habitat suitability					0.546	+	0.038	*				
Distance to other roads					0.562	+	0.045	*				
Nearest Neighbor Nest									0.644	+	0.0292	*

Grayed out boxes = Non significant covariates   Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table 12. Analysis of offending nests relative to nest success

Relationship between Offending Nest and Nest Success				
Natural Substrate Nests				
CHU Group	**Estimate**	**Sign**	**P**	**Sig.**
East CHU	0.13	-	0.875	
South CHU	1.34	-	0.0199	*
West CHU	0.33	+	0.355	
Anthropogenic Substrate Nests				
CHU Group	Estimate	Sign	P	Sig.
East CHU	1.50	-	0.000911	***
South CHU	6.44	+	1	
West CHU	0.70	-	0.004619	**
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1				

Table 13. Significant covariates for natural substrate offending nest across the three CHU groups.

Covariates	West CHU				South CHU				East CHU			
Natural Substrate Offending Nest Drivers												
	EDF	Sign	P	Sig	EDF	Sign	P	Sig	EDF	Sign	P	Sig
Distance to Urban (>20%)	0.844	+	0.007	**					0.7831	+	0.029	*
Distance to Local/Neighborhood Roads	0.574	+	0.069	.								
Distance to permanent bodies of water	0.863	-	0.002	**								
Average breeding season maximum temperature	1.738	+	0.003	**								
Nest Density	0.822	+	0.007	**								
Surface Texture					0.68	-	0.062	.				
Desert Tortoise habitat suitability									0.885	+	0.002	**
Winter Accumulation Precipitation									1.601	+	0.008	**
Grayed out boxes = Non significant covariates Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1												

Table 14. Significant covariates for anthropogenic substrate offending nest success for West and East CHU.

Covariates	West CHU				East CHU			
Anthropogenic Substrate Offending Nest Drivers								
	EDF	Sign	P		EDF	Sign	P	
Distance to permanent bodies of water	0.82	-	0.006	**	0.809	-	0.010	*
Distance to agriculture	0.751	+	0.003	*				
Distance to Main Roads	0.779	+	0.013	***				
Nearest Neighbor Nest	0.6550	-	0.073	.				
Desert Tortoise habitat suitability					0.824	+	0.010	**
Distance to Landfill					1.256	-	0.014	*
Winter Accumulation Precipitation					1.783	-	0	***
Grayed out boxes = Non significant covariates Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1								

Table 15. Rankings of dietary categories by the average percent among Critical Habitat Units. Sites abbreviated the same as in Figure 19. Invert included findings such as: insects, grasshopper, scorpion, and ants. Mammals included any findings such as: hair, fur, and rabbit. Herp included any evidence of reptiles (non-tortoise) such as horns, scales, and rattles. Avian included evidence of feathers or avian bones. Veg (vegetation) ranged from findings such as seeds, apple, nuts, yucca, and wood. Trash included any man-made non-food items such as: plastic, paper, and synthetics. Other was categorized for items found in pellets that were not food items or man-made items such as: rocks, sand, and unrecognizable items. Animal was for non-identified animal parts such as shells, bones, and teeth.

Site	Invert	Mammal	Herp	Avian	Veg	Trash	Other	Tortoise	Animal
CH	24	25	15	5	5	2	0	19	4
CK	58	14	6	3	4	8	7	0	0
FK	27	15	13	15	12	4	10	2	1
JT	16	25	18	17	12	6	1	3	2
MP	26	28	15	11	15	5	2	0	0
OR	23	26	12	9	10	11	2	3	3
PM	23	20	14	25	9	5	0	2	2
PV	26	16	13	21	13	3	8	0	0
SC	28	29	10	13	2	10	6	1	0
Mean	**28**	**22**	**13**	**13**	**9**	**6**	**4**	**3**	**1**

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