MODELING HABITAT SUITABILITY FOR THE CALIFORNIA TIGER SALAMADNER IN SONOMA COUNTY CALIFRONIA

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Abstract

The Sonoma County sub-population of the California tiger salamander (*Ambystoma californiense*) is currently listed as endangered. The main cause of their decline is habitat degradation due to urban development, and agricultural expansion. This study utilizes GIS and geospatial analysis to model suitability of habitat for the California tiger salamander within Sonoma County. The model will predict which areas within Sonoma County contain suitable habitat for the California tiger salamander. It also highlights which areas may need to be further protected to keep the population viable in Sonoma County.

Key terms: California tiger salamander, habitat suitability index, Sonoma County, weighted sum, spatial analysis

Introduction

The objective of this study is to generate a habitat suitability index model for *Ambystoma californiense* in Sonoma County, California. Habitat suitability index (HSI) models primarily rely on field data, and expert knowledge of the species in question to understand habitat requirements. Habitat variables can then be ranked by their relative importance to the species. Data for variables can subsequently be classified according to rank, and then combined to create a final suitability model (Store and Jokimaki 2003). Due to the endangered status of the Sonoma County population of the California tiger salamander, a spatial analysis of precisely where suitable habitat currently exists is crucial for future population management, and restoration. This research will thoroughly examine the current literature on the species to get a better understanding of their habitat requirements, and life history. Based off a review of the literature, a HSI will be created using GIS techniques to predict areas of suitable habitat for the California tiger salamander in Sonoma County. The results will then be synthesized to make recommendations for future conservation, and preservation of the species.

Life History and Habitat Requirements

The California tiger salamander is a terrestrial mole salamander (genus *Ambystoma*) endemic to central California with two distinct population segments (DPS) in Sonoma County, and Santa Barbra County(See Appendix: Fig. A1 and A2). These two distinct population segments diverged from the rest of the tiger salamander population in California during the Pleistocene epoch approximately one million years ago (Shaffer et al., 2004).

California tiger salamanders can grow to be rather large in comparison to other similar salamander species in the region. Adults grow seven to eight inches in length from head to tail. As the figure indicates their tails are flattened on both sides to facilitate swimming. They have broad rounded snouts, stocky bodies, and beady protuberant eyes with black irises. Adults are a blackish brown color with distinct yellow or cream spots. (Loredo et al., 1996). Males can be distinguished from females by their larger size and more developed tail fins. (See Fig. 1)

Figure 1: The California tiger salamander (Ambystoma Californiense)

Annual grassland is the most common habitat for the California tiger salamander, however they can also be found in the grassy understory of valley foothill hardwood habitats, and sometimes, although uncommonly along streams in valley foothill riparian habitats (Shaffer and Fisher 1991). Habitat elevation can range from 3 to 1054 meters above sea level (Jennings and Hayes 1994) however, more recent accounts from the California Department of Fish and Wildlife report that the Sonoma DPS, can be found from 3 to 427 meters above sea level.

Adult California tiger salamanders are largely fossorial, meaning they spend much of the year in underground burrows. They primarily use the burrows of small mammals for cover, especially those of the California ground squirrel (*Otospermophilus beecheyi*). They also occasionally make use of manmade structures for their burrows. Even though they are classified as “burrowing” salamander, they are not known to dig their own burrows. Burrows are critical for the survival of adults, and juveniles through the drier months of the year (Loredo et al. 1996). Leaf litter and, desiccation cracks in soft soil also play an important role in upland habitat cover for the California tiger salamander, and can keep them shielded from the sun, wind which can be fatal if exposed for too long.

Not much is known about the feeding habits of the California tiger salamander, However closely related species of salamanders are known to be "sit-and-wait" predators, preying on earthworms, snails, insects, fish, and even small mammals (Stebbins 1972). Furthermore, aquatic larvae are said to feed on littoral, benthic, and planktonic arthropods as well as insect larvae (Dodson and Dodson 1971).

Vernal pools or ephemeral ponds, are temporary depressional wetlands that occur under Mediterranean climate conditions and are an integral part of the California tiger salamander’s native habitat. These seasonal lowland ponds, facilitate breeding, and provide a place for larval transformation to take place during the late spring and early summer. Adequate rainfall is important to the formation and maintenance of these breeding ponds (Shaffer and Fisher 1991).

Although seasonal vernal pools are preferred for breeding, some populations have been observed, utilizing manmade livestock ponds, and reservoirs.

The warmer rains of November signal breeding season for the adult California tiger salamander. Migrations to breeding ponds usually happen during nights with sustained rainfall between November and February (Shaffer and Fisher 1991). Individuals do not become sexually mature until six years of age (Trenham 1998). Adults will typically live to fifteen years of age on average. Furthermore less than fifty percent of California tiger salamanders breed more than once in their lifetime. Adults normally reside at the breeding ponds for two to three days after breeding, however some individuals can remain there for several weeks. Females lay around 1000 eggs total, typically in clumps of 5-100. The eggs are deposited on submerged, or partially submerged vegetation, and debris (Stebbins 1972).

Larvae complete their metamorphosis into juveniles by late spring or early summer, usually no later than the first week of July. Larvae are known to prefer turbid water, and seek cover in clumps of vegetation, and other submerged debris. Upon completion of their metamorphosis, juveniles will spend anywhere from a few hours to a few days near the edge of the pond before dispersing from their breeding sites. Dispersal from breeding ponds, back to upland habitat typically occurs during the evening (Jennings and Hayes 1994).

From 1996 to 1997 Trenham (2001) conducted a radio tracking study on a California tiger salamander population located in the upper Carmel Valley in Monterey Bay County California. The study was intended to determine an appropriate terrestrial habitat buffer for the California tiger salamander. The results of the five month study concluded that "any plan to maintain local populations of California tiger salamanders should include vernal ponds surrounded by at least 173 meter wide buffers of terrestrial habitat with burrowing mammals."

Adult California tiger salamanders are not known to be territorial, however larvae may compete with, and prey on other amphibian larvae. Adults are not known to be subject to heavy predation. This is mostly due impart to their fossorial, and largely nocturnal lifestyle. Larvae however may fall prey to waterfowl such as herons, and egrets. Garter snakes have also been known to prey on larvae. Larvae of California tiger salamanders are rarely found in ponds with predatory fish (Shaffer and Fisher 1991)

Threats

The main threat to the survival of the California tiger salamander in Sonoma County is conversion of native grassland, and vernal pool habitat to urban, and intensive agricultural uses. As of 2001 suitable habitat for the species has dwindled to a few small pockets in West Santa Rosa, South Santa Rosa, and West Cotati. California grasslands, oak woodland and vernal pools remain some of the most endangered habitats in the world. It is estimated that a mere one tenth of one percent of native grassland still remain in California. (Jones and Stokes 1987, Shaffer et al. 1993).

A 1990 study by Waaland et al, found that twenty five percent of a 28,000 acre area in the Santa Rosa Plain had been converted to "medium sized ranch-style houses, golf courses, and commercial buildings. Furthermore, the study also found that another seventeen percent of that area had been converted to intensive agricultural use. Vineyard development has also posed an imminent threat to the survival of the California tiger salamander in Sonoma County. Grape production requires the use of a technique known as deep slip plowing. This process uses a five to seven foot plow to break up hardpan. Hard pan is a dense layer of soil that prevents water percolation, and facilitates the formation of vernal pools. Vineyards are regularly plowed and disced once planted. Repeated discing, and deep slip plowing have been shown to permanently alter soil hydrology, and have resulted in reduced suitable habitat for the California tiger salamander in Sonoma County.

This study addresses the problem of habitat degradation for the California tiger salamander by spatial modeling where current suitable habitat occurs for the California tiger salamander within Sonoma County. Wildlife habitat relation (WHR) models serve as an important method for determining where species occur, and in what type of habitat they occur in. However this method can be prone to some error. In a 1996 study, Edwards at el, reported that habitat relationship models tend to over-predict rather than under-predict species distribution particularly when it comes to reptiles and amphibians. In that particular study, the mean accuracy for amphibians was 69.42%. It should be noted however that the study was relatively narrow in scope including only eleven species of amphibians in the Colorado Plateau region of Utah.

Methods

All of the data for this research was sought, and retrieved via Google's search engine and ArcGIS Online. Data was imported, managed, and analyzed using ESRI's ArcMap software version 10.4.1, in addition to Microsoft Excel. The USGS National Map provided the digital elevation model (DEM) component for this project. The raw data for Sonoma County's elevation came in two separate 9.4 x 9.4 cell size raster tiles which were then mosaicked together and clipped to the extent of Sonoma County, using a shapefile of Sonoma County from the National Atlas of the United States. The projection used throughout this project, was NAD 1983 Californian Teale Albers, which contains the North American 1983 datum, and has its linear units in meters.

Based on the Sonoma County DEM, two derivative products were calculated using the spatial analyst tool box; these included both slope, and hillshade. The next set of data collected and prepared for analysis was the USDA Forest Service CalVeg Vegetation layer. The raw CalVeg data was initially partitioned into two separate shapefiles that encompassed the area of Sonoma County, and beyond (North Coast West, and North Coast Mid). These two shapefiles had to be merged together and clipped to the extent of Sonoma County for analysis. The resulting shapefile was then symbolized based on its Wildlife Habitat Relationship Type (WHRTYPE) unique value field.

The next step was to find suitability ratings of habitat types for the California tiger salamander. This data was available from the California Department of Fish and Wildlife's Habitat Relationship database or (CWHR). The data was contained within an excel document with, each species having a unique identification number, A001 being the ID for the California Tiger Salamander. For each habitat type (which are defined by the CWHR) a suitability rating between 0 and 1 was given for cover, feeding and reproduction. The suitability ratings came preassigned from the CWHR database, and are based on observations and analysis by the CA

Department of Fish and Wildlife. These values were then averaged together in a column labeled average suitability. It was then possible to create a pivot table to display an average suitability for each type of habitat. (See Fig. 2).

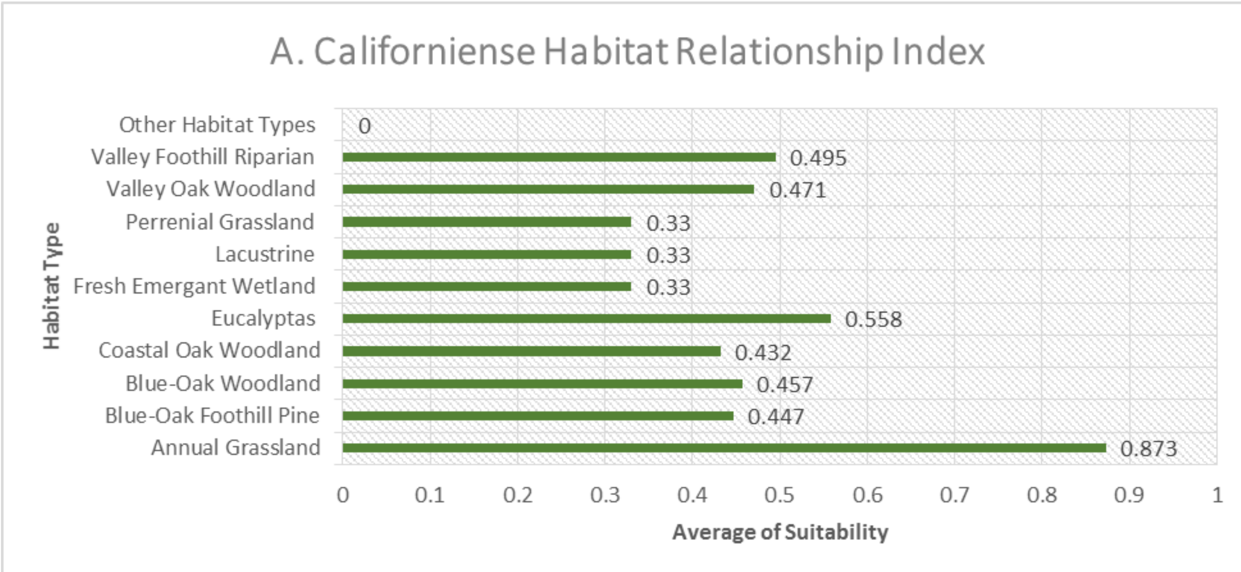

Figure 2: Graphical visualization of a pivot table for habitat type and average of suitability (CWHR)

Next it was necessary to give all of the types of habitat that were not present in the table the value of zero, as they were unsuitable habitat for the California tiger salamander. With all of the other habitat types filled in, and given a value of zero, the table was saved as a .csv file and imported into the project geodatabase. The suitability table then had to be joined to the Sonoma CalVeg layer. However before this step it was necessary to change the decimal precision of the suitability table to floating point so that no precision was lost. The join was done based on the common field of (WHRTYPE and HAB_CODE) these fields in both data sets contain the same abbreviated codes for habitat type. This join resulted in a new field in the Sonoma CalVeg layer called, average of suitability.

With this new field it was then possible to convert the Sonoma CalVeg polygon layer to a raster, based on the average suitability field. The resulting raster contained values ranging from 0 to 0.8725 signifying the average of suitability for each kind of habitat throughout the county. The next set of data that was imported into ArcMap was a vector layer from the California Natural Resource Agency showing the distribution of vernal pools in California. Furthermore it was necessary to import a vector layer of the habitat range of the California tiger salamander. Both the vernal pool layer and the habitat range layer were clipped to the extent of Sonoma County and then projected.

After both layers had been clipped to Sonoma County and projected, the vernal pool distribution layer was clipped to the Sonoma CTS habitat range layer. This resulted in a vector layer of vernal pool distribution within the habitat range of the California tiger salamander in Sonoma County. Next a new field was added to the table of the newly created vernal pool distribution layer. For simplicity the field was labeled ADD and all rows were assigned the value of zero using the Field Calculator. The reasoning for this is to give the areas that contain vernal pools a number value while the areas that do not contain vernal pools have a "no data." Next this vector layer was converted to a raster using the Polygon to Raster tool, the conversion was done based on the value field ADD, previously assigned to the vector layer. This produced a raster of areas that contained vernal pools with the pixels valued at zero and all other areas valued at "no data" however this raster had to be clipped once again the extent of Sonoma County as the "no data" values reached beyond the study area.

Next the Sonoma VegMap data was imported into the data catalog, the folders contained a shapefile for land use and a raster layer of canopy density. These two data sets were subsequently clipped and projected appropriately. For the land use layer it was necessary to select those land use types that were *not* suitable for the California tiger salamander and give them a value of 0 using the field calculator. These land use types included; annual cropland, barren/sparsely vegetated, developed, intensively managed hayfield, irrigated pasture, major roads, nursery/ornamental horticulture, orchard /grove, perennial agriculture, urban window, vineyard and vineyard replant. The polygons were exported to a new feature class then converted to raster format based on the new field.

The next data set imported into ArcMap was the USDA Natural Resource Conservation Service Soil Survey (SSURGO) soil data. The raw shapefile data for Sonoma County was split into four separate sub basins; Russian River, San Pablo Bay, Tomales/Drake Bay and Gualala Salmon. To streamline and automate the processing of the data, a model was created using ArcMap's Model Builder to merge, clip and project the data, so that it was utilizable in the analysis (See Fig. 3)

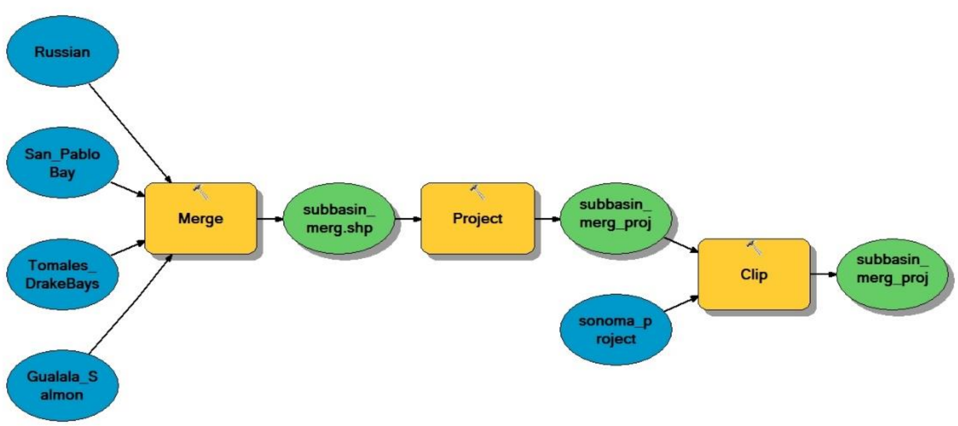

Figure 3: Flow diagram for automating sub-basin soil data in Model Builder.

The final output of the model was a shapefile containing all four sub-basins clipped to the extent of Sonoma County. The resulting shapefile was then symbolized based on the value field, of ponding frequency. The value field came pre-classified in a binary fashion with 0 – 14% representing the low ponding frequency of the soil and 75 to 100% signifying high ponding frequency.

The last set of data imported into ArcMap was a vector layer of protected areas within Sonoma County, courtesy of Sonoma Open Space District. To prepare this layer for analysis it was first projected to the proper coordinate system, and clipped to the habitat range of the California Tiger Salamander. Then using the select tool, eight protected area polygons were selected. These eight areas were selected because, they are ecological preserves owned by the California Department of Fish and Wildlife and closed to the public. Next in a similar fashion to the vernal pools layer a new field was added to the attribute table. Again for simplicity the field was labeled ADD and all rows were assigned the value of 0 using the Field Calculator. Next this layer was converted to a raster using the Polygon to Raster tool, the conversion was done based on the value field ADD, previously assigned to the vector layer.

This produced a raster of areas that contained the eight selected protected areas with the pixels valued at zero and all other areas valued at “no data” however this raster had to be clipped once again the extent of Sonoma County as the “no data” values reached beyond the study area. The Reclassify tool was then used to set pixels with the value of zero to one and pixels with “no data” to zero. The output of this tool produced a raster with eight protected areas all with the value of one, signifying good location, and habitat for the California Tiger Salamander.

Using Model Builder, a habitat suitability index model was created that incorporated all layers. (See Fig. 4)

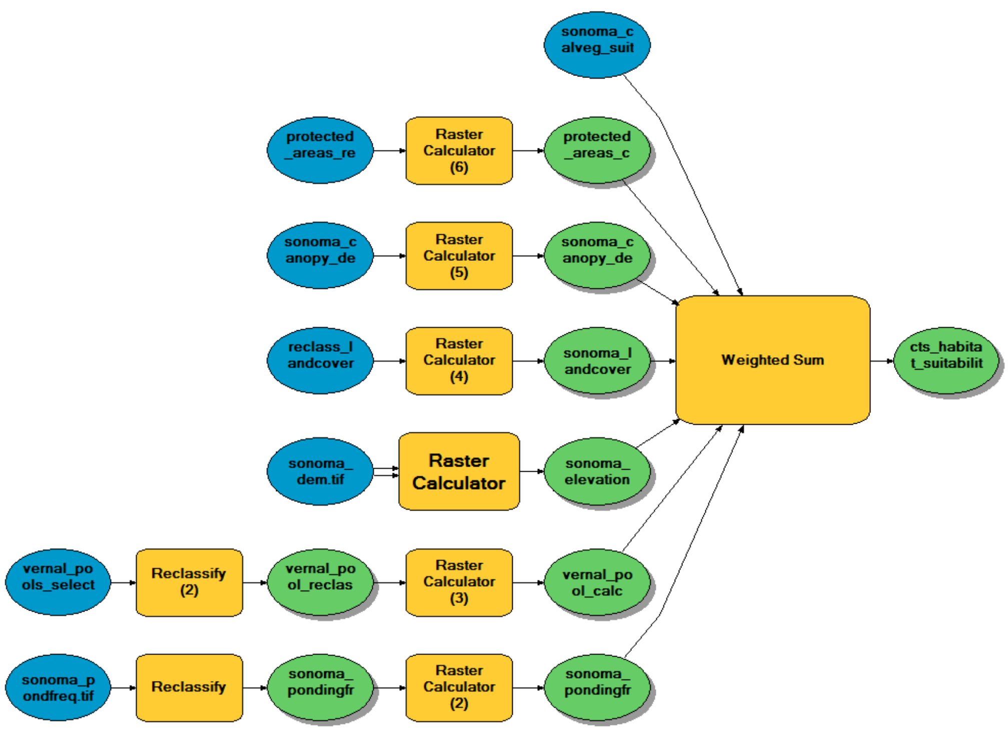

Figure 4: Flow diagram for final habitat suitability index in Model Builder

The Weighted Sum tool was used to weight each layer according to how significant it is to habitat for the California tiger salamander. The weights on a range of 0-100%. The CalVeg layer was first weighted at 20%. A relatively high weight for vegetation was given because, habitats like valley foothill oak, and especially annual grasslands are crucial to the Tiger salamander's lifecycle. Then suitable elevation was calculated using the Raster Calculator tool. The elevation parameter was set to equal greater than three meters but less than 217.7 meters above sea level, this is because 217.7 m is the highest elevation the species occurs at within their range in Sonoma County. Elevation was then weighted at 7% because elevation plays a key role in the formation of vernal pools. Next the vernal pool layer had to be reclassified so that the values of where pools do occur are equal to one and areas where they do not occur are equal to zero. The Raster Calculator tool was then used to set the reclassified layer to 1 and then it was weighted at 38% as it is perhaps the most important feature of habitat for the California tiger salamander, facilitating the breeding and propagation of the species.

Using the Raster Calculator tool again, the reclassified land use layer was calculated to be equal to 0, which signifies land that does *not* fall under the classification of the following; annual cropland, barren/sparsely vegetated, developed, intensively managed hayfield, irrigated pasture, major roads, nursery/ornamental horticulture, orchard /grove, perennial agriculture, urban window, vineyard and vineyard replant. The resulting output was then weighted at 24%, higher than the elevation weight but lower that the vernal pool weight. The ponding frequency layer was first reclassified so that the 0 – 14% value was set to zero and the 75 – 100% value was set to one. From there the Raster calculator was used to have ponding frequency be equal to one. This layer was then weighted at 2.5%.

Next the Sonoma Vegmap canopy density layer was brought into the model, the Raster Calculator tool was used to set canopy density to less than or equal to 180 (254.8 being the highest) which covers a good middle ground in terms of canopy cover for the California Tiger Salamander. A value of zero to moderate canopy cover makes sense for the Tiger Salamander because of their relationship with the California ground squirrel which require some canopy cover for their habitat. The calculated layer was then weighted to 2.5%.

The last layer to be weighted in the model was the rasterized protected areas layer. The raster calculator was used to choose those values equal to one. The output layer was then weighted at 6% as these selected protected layers are considerable valuable habitat for the California tiger salamander because they are safe from development and closed to the general public. The entire model was then validated and checked for scripting errors, and ran successfully.

Results

The output of the weighted sum model, produced a final habitat suitability index map for the California tiger salamander in Sonoma County (See Fig). Suitability values are ranked from zero to one with decimal precision, and symbolized with by a stretched value, chromatic color ramp. Blue (0) symbolizing unsuitable habitat, and red (0.9745) signifying high quality suitable habitat. The stretched type was changed to maximum-maximum. This stretch type applies a linear stretch based on the output minimum and output maximum pixel values, which are used as the endpoints for the histogram. This made the features in the output suitability raster easier to distinguish as the pixel values were distributed across the entire histogram range which brightened and increased the contrast of the image. (See Fig. 5 & 6)

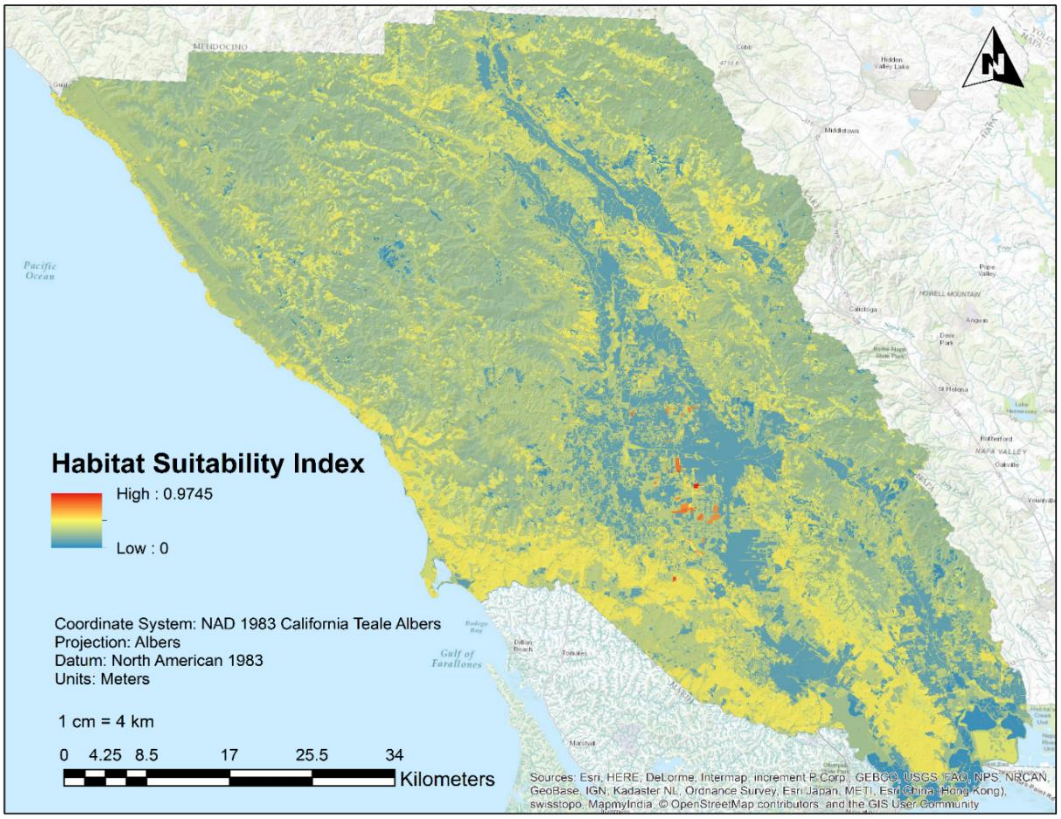

Figure 5: Habitat Suitability Index Map for the California tiger salamander in Sonoma County (full extent)

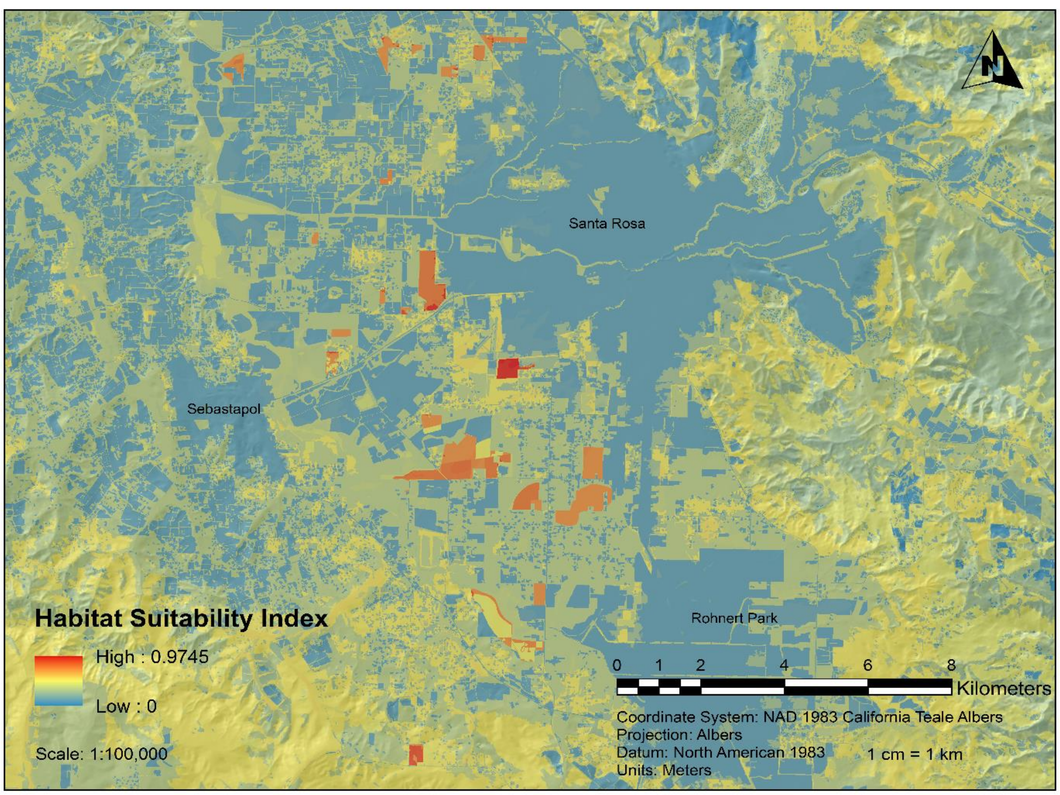

Figure 6: HIS Map (Zoomed)

The average suitability rating for the whole of Sonoma County is 0.262 which is very low. The model returned a total of 30 sites with a suitability rating above 0.70 (Orange-Red). For the purposes of this research, a "site" will be defined as an area roughly 5 to 180 acres in size within the home range of the California tiger salamander and has a majority of its area valued with a suitability rating above 0.70 (Orange-Red). Urban and residential areas as predicted yielded very low suitability ratings, none higher than, 0.095 (Blue). The same was true for agricultural use areas, annual cropland, and vineyards for example scored very low in terms of suitability for the species.

Higher elevation native forest regions similarly did not return particularly high suitability ratings, ranging from around 0.20 – 0.30 (Bluish-Yellow). Grassland areas throughout Sonoma County conversely faired moderately well, having ratings at or near 0.50 (Brighter Yellow). Much of the southern portion of the California tiger salamanders range produced a rating of 0.50 which signifies moderately suitable grassland habitat.

Areas that scored above 0.70 (Orange-Red) did so because they contain both, vernal pools and relatively undisturbed annual grassland habitat and oak woodland. However as the figure shows number of substantially suitable sites are in close proximity to urban or agricultural areas (Blue). There are two sites in particular that are of interest to this study. One is located on Roblar Drive in Petaluma and the other located off Ludwig Ave. in Santa Rosa. The Roblar Drive site has a high suitability rating of 0.889, and the Ludwig Ave site has value of 0.974 the highest one returned from the model. The Ludwig Ave. site is currently protected by the California Department of Fish and Wildlife and is closed to the public. On the other hand the Roblar Drive site currently is privately held and unprotected by any agency. Furthermore there are another 21 sites that have a rating at or above 0.70 that are currently unprotected.

Discussion

As evidenced by the results of the analysis, it is clear that suitable habitat for the California tiger salamander is under immediate threat. Much of their current habitat range is unsuitable for the species' continued survival, due to urban development and agricultural expansion. The few remaining locations of high habitat suitability are relatively small in size and disjoined from one another. The 173 meter upland habitat buffer for the California tiger salamander suggested by Trenham et.al (2001), is near impossible to maintain for a most of sites in this analysis, as they are surrounded or, very near urban developments or agricultural operations.

The results of this analysis highlight thirty suitable sites for the California tiger salamander to feed, and reproduce and seek cover in, of these thirty sites nine are currently have some form of protected status. This leaves twenty one sites that contain highly suitable habitat, completely unprotected from future development and agricultural expansion.

To see the continued survival of the California tiger salamander in Sonoma County, it would be immediately necessary to designate more protected areas in regions with highly suitable habitat for the species. The twenty one currently unprotected sites identified in this study would make excellent candidates for designated protection in the future. Organizations like the California Department of Fish and Wildlife, The Laguna de Santa Rosa Foundation, and the Sonoma Open Space District would find the results of this study useful to know where future protection efforts should be aimed towards.

This study provides a geospatial representation of where restoration efforts could potentially be focused on the near future. Recovery goals for the species should include the restoration of habitat conditions to sustain a viable population and, to support the species self-sufficiency in the long term. Another recovery objective should be to protect and manage current suitable habitat to ensure that the species is able to adapt to future threats such as climate change. Moreover, restoration of the species should also include re-introduction of individuals to effectively establish new populations in historically occupied areas within the current habitat distribution range. Finally the species population trends need to be monitored closer and across multiple years to determine if populations are sustainable.

Due the heavy reliance on computer based GIS data and software, the results of this study can in no way account for every biotic and abiotic factor that correspond to suitable habitat for the California tiger salamander. Because of this there is some margin of error that comes with a geospatial analysis of this nature thus, field evaluations of predicted sites would be useful for further research. However, even though this study could not account for all environmental and human factors that make up suitable habitat for the species in question, it nevertheless could serve as a useful tool in future restoration efforts. It highlights the damage that has already been done, and makes it clear that there is work that needs to be completed to preserve the California tiger salamander in Sonoma County.

Conclusion

Sonoma County is uniquely positioned to take action on saving the California tiger salamander and, fostering biodiversity. The county has a fairly good track record of robust environmental initiatives, and dedication to preserving open space. As aforementioned there are a number of organizations and agencies that could potentially spearhead recovery efforts, and also mitigate the damage that has already been done to the species. It remains to be seen if action will be taken to bring Sonoma's population of the California salamander back from the brink of extinction or if this population will become yet another causality of the Anthropocene extinction.

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Data Sources and Credits

- Sonoma Vegmap – Landcover, Canopy Density
- USDA Forest Service CalVeg- Vegetation
- CA Dept of Fish & Wildlife, California Wildlife Habitat Relationships – Vegetation Suitability Table
- California Natural Resource Agency - Vernal Pool Distribution
- Sonoma Open Space Distirict – Protected Areas
- USDA Natural Recource Conservation Servie Soil Survey (SSURGO) – Ponding Frequency
- National Atlas of the United States – Sonoma County Boundary

Appendix

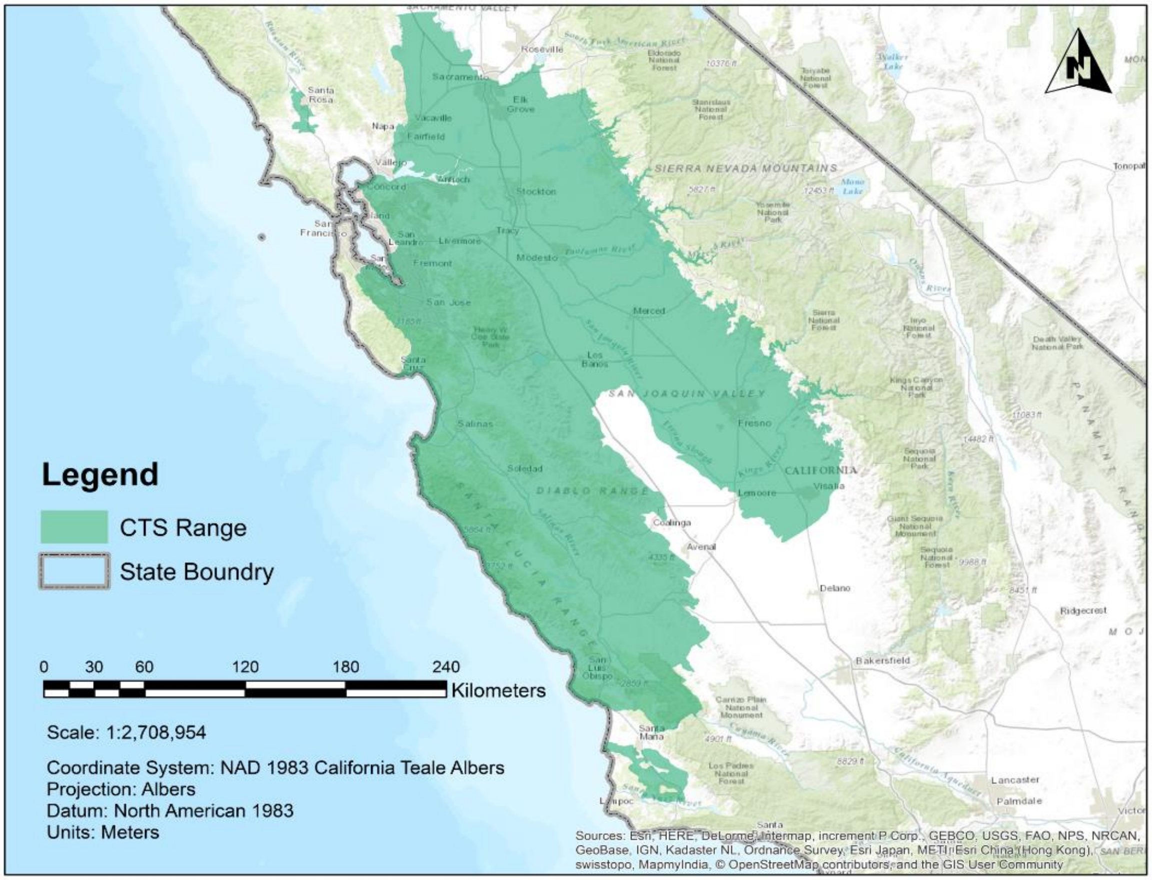

Figure: A1

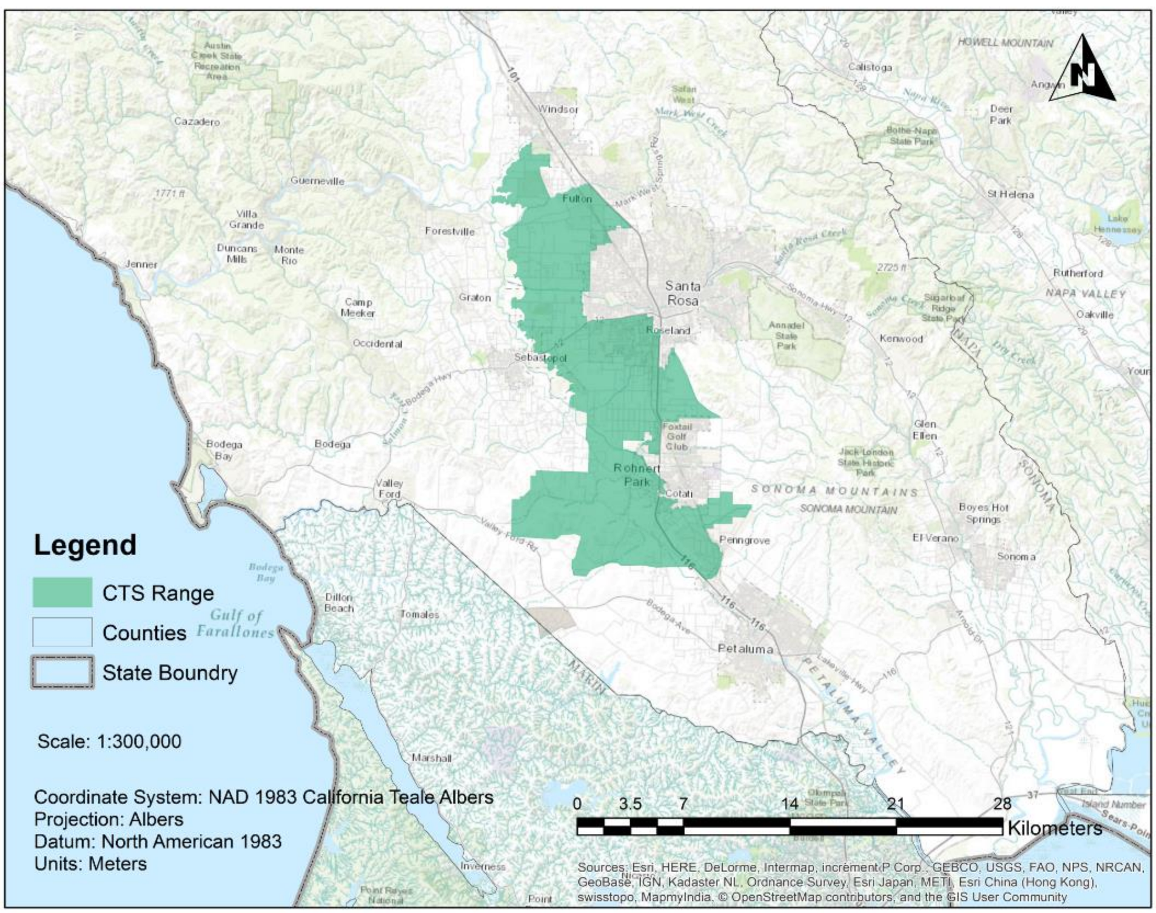

Figure: A2