An Assessment of Endangered, Threatened, and Species of Special Concern in the University of California Natural Reserve System

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1 Abstract

The mission of the University of California Natural Reserve System (UCNRS) is to preserve California's biodiversity, advance scientific research, and enhance public outreach, yet no studies have been conducted to holistically assess how effective the UCNRS is in accomplishing their goals. Our aim was to conduct a study that measured the UCNRS's success in protecting endangered species. We compiled a list of threatened, endangered, rare and species of special concern in California and used it to identify which and how many imperiled species exist within the UCNRS according to their own provided species lists, downloaded museum localities, and MaxEnt models. The MaxEnt models were produced using climate data, downloaded museum localities, and two thresholding methods, the minimum probability and maximum sensitivity plus specificity (max SSS) approaches. The max SSS method generally produced more realistic results, however some species natural ranges fell between the ranges produced by either methods. The model was found to be strongly contingent on museum locality data. Although we were only able to complete the analysis for amphibian taxa, we did develop a streamlined protocol for assessing the remaining taxon. According to our results and ecoregion data we constructed recommendations for future UCNRS sites for amphibian preservation. According to our analysis, the areas north and south of the San Francisco Bay as well as the central valley near Sacramento demonstrated high suitability for new NRS sites. The mountains surrounding the central valley, however, showed low suitability. We based these recommendations on the coverage of current sites of threatened and endangered species as well as its coverage of California's ecoregions. We recommend the UCNRS acquire sites in these suitable areas in order to further its goal of protecting California's biodiversity.

2 Introduction

The University of California's Natural Reserve System (UCNRS) helps to preserve California's natural landscape and native species by limiting development. Although the reserves encompass diverse climates, the UCNRS lacks a comprehensive threatened and endangered species list, which is a instrumental in properly evaluating their effectiveness in preserving California's biodiversity.

Our research serves to gauge the biodiversity found in the UCNRS by investigating endangered species lists, museum records, and UCNRS data, as well as utilizing modeling techniques. The purpose of the study is to foster the use of the UCNRS as a cutting-edge research resource, as well as promote collaborative work between the UC campuses. Our initial goal was to produce a system wide UCNRS comprehensive list of endangered, threatened and species of special concern. The research evolved to assessing the accuracy UCNRS species lists by comparing the acquired reserve lists with museum localities and MaxEnt predicted species ranges. The overall goal of our project was to answer the following research questions:

1. Does the UCNRS encompass many threatened, endangered, rare and species of special concern?

2. How effective is the UCNRS in protecting threatened, endangered, and rare species as well as species of special concern from anthropogenic threats?

3. Will the UCNRS be able to protect these species against future or long-term threats such as climate change?

Resolving these questions sets the informational foundation the UCNRS requires for conducting research on its endangered, threatened, and rare species.

Before conducting the research on all taxonomic groups, we ran a pilot study on amphibians to refine the methodologies and develop a protocol. We chose amphibians because they are indicator species, highly sensitive to climate perturbations. Additionally, our advisor, Brad Shaffer is a leading herpetologist and was able to assess the accuracy of the pilot results to determine the effectiveness of the methodology.

2.1 The University of California Natural Reserve System

In the 1950s, it became evident that a large portion of California's land used for research and academic learning was being lost due to population increase and development. In response, professors and researchers from across the UC system brought up their concerns to the UC Office of the President. In 1965, the regents of the University of California established the Natural Land and Water Reserves System, which contained 7 initial reserves (Fiedler et al. 2013). It is now referred to as the University of California's Natural Reserve System. The UCNRS is composed of 38 sites that covers more than 750,000 acres, making it the largest university-affiliated natural reserve system in the world (Figure 1). The UCNRS is holdings in one of the most physiographically diverse regions in the U.S., containing twelve different ecological regions (Fiedler et al. 2013). Each site is unique with viable ecosystems representing California's most characteristic habitats.The UCNRS land is a combination of owned land and land use agreements formed with other entities.The sites are acquired through various donors and partnerships, therefore are not necessarily considered areas optimal for conservation. It is probable that endangered taxa are not being adequately protected because their ranges only partially occur in the UCNRS sites. Although the reserves are acquired at a system wide scale, they are managed at a campus level, which helps to integrate them into university instruction and facilitate research.

2.2 California Imperiled Species List

The Federal Endangered Species Act list, California Endangered Species Act list, California Species of Special Concern lists, and the California Native Plant Society Inventory of Rare, Threatened, and Endangered Plants of California were combined to produce the California imperiled species lists. The four different types of lists were chosen for their inclusiveness and comprehensivity, specifically for the state of California (Table 1).

2.2.1 Federal Endangered Species Act

The Federal Endangered Species Preservation Act (ESA) was first created in 1966 to conserve imperiled species and their ecosystems. Not until 1973, however, when a Convention on the International Trade in Endangered Species of Wild Fauna and Flora (CITES) was called in Washington, D.C., did the list gain international protection, particularly in regards to commerce (U.S. Fish and Wildlife Services 1973).

The federal list of Endangered and Threatened Wildlife and Plants is administered by the U.S. Fish and Wildlife Service (FWS) and the Commerce Department's National Marine Fisheries Service (NMFS) under the ESA. The list covers all taxonomic groups, but excludes pest insects. Species are listed as either endangered, which indicates that they are in danger of extinction in the majority or their ranges, or threatened, which denotes that they have a high probability of becoming endangered in the near future. To be eligible for listing, evidence must suggest that the species is significantly affected by one of the five criteria: damage to habitat, overutilization of species for commercial, recreational, scientific, or educational purposes, disease or predation, lack of protection, or afflicted by other anthropogenic threats (U.S. Fish and Wildlife Services 1973).

Since federal agencies oversee the list, changes to listings must be made using rulemaking procedures; therefore listing a species is uncommon due to the time the process requires. Even if a species meets listing criteria, conservation priorities are the determining factor in the species' listing. The priority of protecting a species is determined by degree of threat, immediacy of threat, and taxonomic distinctiveness. If species are not of high enough priority they may be considered for the candidate species list. Unlike the endangered and threatened species list, the candidate species list has no legal protection. Instead, the FWS and NMFS work with both the private and public sectors affecting the species survivorship to develop a conservation agreement that is aimed to prevent the species from being listed. Currently, 315 of California's species are listed on the endangered and threatened list, while 23 are found in the candidate list (U.S. Fish and Wildlife Services 1973).

2.2.2 California Endangered Species Act

The California Endangered Species Act (CESA), under the California Fish and Game Codes was created in 1984 and is regulated by the California Department of Fish and Wildlife (CDFW) and the California Fish and Game Commission (CFGC). Species are evaluated on the basis of habitat damage, competition, predation, disease, overexploitation, and other natural or anthropogenic factors. Only native California species are included in the CESA inventory (State of California Department of Fish and Game 1984).

Species that are candidates could be classified as endangered, which indicates the species is facing serious threats to extinction in a majority of its ranges, or threatened, which declares the species is at risk of becoming endangered in the foreseeable future if no preventative actions are presently taken. The CESA list is reevaluated and a status report is generated January 30 every three years to maintain relevancy. Currently the list includes 79 animals and 221 plants (California Department of Fish and Game 1984).

The California Department of Fish and Game also runs the California Natural Diversity Database, CNDDB. The CNDDB keeps track of rare animals, plants, and natural communities in California (California Natural Diversity Database 2011). The Nature Conservancy (TNC) began the CNDDB in 1970's and now it's overseen by NatureServe. The "Special Animals List" includes all taxa the CNDDB is concerned in monitoring, despite of their legal or protection status. These species are "Candidates" for state listing or "Proposed" for federal listing (California Natural Diversity Database 2011). The taxa on this list meet the criteria for listing, but might not be listed on any list. The taxa on this last are considered for the Species of Special Concern list.

2.2.3 California Species of Special Concern

California Species of Special Concern (SSC) listings are species that are not formally on the CESA endangered species list, however fit one of five criteria that suggests the species requires more protection. The species qualifies for listing if it lacks a viable population within the state, is federally but not state listed, meets the endangered or threatened criteria in the CESA, is experiencing significant range or population decline that without preventive measures will lead to CESA listing, or is comprised of naturally small populations that are highly sensitive to changing conditions. The SSC takes a preventative approach to protecting species. Although the SSC has no legal backing, the list serves to bring attention to imperiled species to legislative agencies, regulatory bodies, the scientific community, and the general public. Currently, the SSC includes listings for mammals, birds, reptiles, amphibians, and fish. The SSC is compiled by contracted leading experts and maintained by California Department of Fish and Game's Biogeographic Data Branch (Comerack et al. 2008).

2.2.4 California Native Plant Society

The California Native Plant Society (CNPS) inventory of Rare and Endangered Plants began in 1968 as card files. G. Ledyard Stebbins, President of the CNPS at the time, compiled data cards of 80 plants within his research area and distributed it amongst members of the CNPS. Since 1968, the species card files expanded, eventually transforming into a list format. In 1971 the first list was distributed, while in 1974 the first inventory was published. The 6th edition was the last inventory to be published, although the CNPS is currently on their 8th edition, which was released in 2010. The last two lists were kept virtual to enhance the user's experience, accessibility, and relevance (California Native Plant Society 2010).

Originally the inventory was reviewed and updated every five to seven years; however, due to technological development and widespread use of the internet, CNPS realized that publishing a new edition every few years sacrificed the inventory's relevancy. Therefore, they shifted to a "continuous data analysis and dissemination" approach, in which the inventory is constantly under review and updated quarterly. In the inventory, the species are placed into a five category ranking system (California Native Plant Society 2010):

1A) "Presumed dead in California"
1B) "Plants, Rare, Threatened, or Endangered in California and Elsewhere"
2) "Plants Rare, Threatened, or Endangered in California, But More Common Elsewhere"
3) "Plants About Which We Need More Information - A Review List"
4) "Plants of Limited Distribution - A Watch List"

In addition to rank, the species are assigned an endangerment level, which ranges from 0.1 to 0.3. A rank of 0.1 indicates that more than 80% of that species's population is at risk, 0.2 designates that 20-80% are at risk, while 0.3 suggests that less than 20% are at risk (California Native Plant Society 2010). Due to the list's comprehensivity and relevance, the CNPS Rare Plant Inventory is the primary list used to compile the plant portion in our California imperiled species list.

3 Methods

We conducted our research in three phases. The first phase dealt with data acquisition and preparation; in this step the raw data were formatted and converted into a usable format. The second stage focused on processing the data and running the analysis. The last step of the research was interpreting the results and producing the products (Figure 2).

3.1 California Imperiled Species List Compilation

The Federal Endangered Species Act list, California Endangered Species Act list, California Species of Special Concern lists, and the California Native Plant Society Inventory of Rare, Threatened, and Endangered Plants of California were combined to produce the California imperiled species lists (Appendix 1A). The list includes mammals, birds, reptiles, amphibians, insects, and plants. We excluded marine animals, including saltwater fish, due to the limited number of UCNRS sites that contain a marine habitats. We also excluded migratory birds because their presence in California is seasonal.

The flora portion of the California imperiled species list is comprised of plants ranked 1B, 2, and 4 in CNPS eighth edition of California native plant society inventory of rare and endangered plants (CNPS 2010). We excluded plants with a 1A rank because they are already presumed extinct and rank 3A plants because they are not necessarily rare, but lack information or may be experiencing synonym issues. Additionally, we removed non-vascular plants because the UCNRS flora list did not include them.

3.2 UCNRS Species List Compilation

3.2.1 Fauna

The UCNRS fauna list was compiled using the information available on the UCNRS and individual reserve websites. We also contacted reserve managers to obtain any additional information. Collecting fauna lists was a challenge because lists were often incomplete or entirely missing. For example, the only information accessible for Box Springs Reserve is their web page, which has no official species list. It only states that 19 reptiles, 16 mammals, and 85 birds occur on the reserve, without naming all of the specific species.

After we gathered the available fauna information, we input the data into a table. The table is organized first by reserve, then by taxa. We also input information on the taxonomic name listed by the reserve and known synonyms (Appendix 1A).

3.2.2 Flora

The most updated UCNRS flora list was created in 2008 by Brian Haggerty and Susan Mazer from the University of California, Santa Barbara and available online (Haggerty & Mazer 2008). Although the flora list was the most comprehensive in comparison to the other taxon, it still required refining for our analysis. The flora list had 10126 entries and stated that 3300 unique species existed within the UCNRS; however, about 20% of the entries contained either spelling or duplication errors. Additionally, the Sagehen Creek Reserve indicated they had a more updated flora list. Therefore, any Sagehen Creek Reserve entries in the UCNRS flora list were substituted out.

To correct the spelling errors and standardize the formatting, the UCNRS flora names were updated to the accepted names in the second edition Jepson Manual (TJM2) (Baldwin, Goldman, & Vorobik 2012). The species names as listed in the UCNRS flora list were put into the the Jepson Dynamic Concordance tool, which outputted the currently accepted TJM2 (University of California Berkeley 2009). The tool is only able to produce the updated names if the input names are found in Jepson Manual 1993 (JM93) (Hickman 1993). Therefore, any names that the Jepson Dynamic Concordance did not find were manually searched through the Jepson Interchange to verify that the name was not an accepted name in JM93 (University of California Berkeley 2009). Next, the name was inputted into CalFlora's online database, which was able to provide all the accepted names found in TJM2, JM93, and the United States Department of Agriculture (USDA) Plants database (CalFlora 2013). Since the TJM2 and JM93 names did not exist according to the Jepson Interchange, the CalFlora search only yielded names listed in the USDA Plants database (USDA 2013). Subsequently, the names were inputted into the USDA Plants database to verify that it was the latest name used by the USDA and then updated in the UCNRS flora list. An R script was then run to delete all the duplicates.

3.3 UCNRS Endangered Species List

3.3.1 Amphibians

Before merging the updated UCNRS imperiled species list and the California amphibian synonym list, the amphibian section of the UCNRS imperiled species list was spell-checked and pulled out. A column for the genus species (no subspecies) name was added to both lists. The 'merge' function in R (R Development Core Team, 2013) merged the two datasets based upon the genus species columns, which resulted in the UCNRS endangered, threatened, rare, and amphibians of special concern list, since the query selected for only amphibians found in both lists.

3.3.2 Flora

When comparing the updated UCNRS flora list with the California Imperiled Species List plant section, the plant section was extracted from the list and another column was added for TJM2 names. The addition of the TJM2 names ensured the UCNRS flora list and the California Imperiled Species List plant names were in the same format. The names in the California Imperiled Species List plant list were updated in the same method the UCNRS plant list names were updated. The plant names were first inputted into the Jepson Dynamic Concordance, then the Jepson Interchange, followed by CalFlora, and lastly in the USDA Plants database (University of California Berkeley 2009; CalFlora 2013; USDA 2013). Some varieties species were lost from the list because their names changed to species level. After all the names were formatted, R was used to merge the two lists according to formatted names. The result was the UCNRS rare flora list, since the query selected for only plants found in both the updated UCNRS flora list and the California Imperiled Species List flora section.

3.4 Downloading Localities (walk through all steps)

3.4.1 Amphibian (GBIF)

Before using R to download georeferenced locality data from the Global Biodiversity Information Facility (GBIF), an issue of synonymy needed to be addressed. In GBIF, locality data is searched by the organism's name, therefore when a particular organism had or has multiple names, the search becomes more complicated. For example, the California red-legged frog was listed as *Rana aurora draytonii* before 2004, but after 2004 changed to *Rana draytonii* because the organism was recognized as a distinct species from *Rana aurora* (Shaffer et al. 2004). To deal with the these taxonomic issues and ensure a thorough localities search, an all-inclusive synonym list for each organism was generated. Therefore, for *Rana draytonii*, *Rana aurora draytonii* was added to the synonym list in case the locality was entered into the database prior to 2004. Another example is the arroyo toad, which has three synonyms. The organism was initially named *Bufo microscaphus californicus*, however approximately 15 years ago, it became a distinct species from *Bufo microscaphus* and renamed *Bufo californicus*. Then in 2006, its genus was changed to *Anaxyrus* and is currently recognized as *Anaxyrus californicus* (Frost et. al 2006). All the synonyms for each organism was searched to obtain all possible localities from GBIF.

Once the synonymy matter was resolved, GBIF locality data was downloaded using R. Both the "dismo" and "XML" data packages were used to accomplish this task. "Dismo" is a species distribution modeling function that predicts entire geographic distributions from occurrences at a number of sites. The function "gbif" is embedded in the package "dismo", which enables R to downloads species occurrence records directly from the GBIF data portal. "XML" is a function for tools parsing and generating XMLs.

Initially the locality data was downloaded on a species level because subspecies are often misidentified and can be unreliable. Localities for organisms listed as a subspecies on the UCNRS imperiled species list, consequently included some localities that did not particular belong to the subspecies. Thus, producing ambiguous data and over inflated ranges in the downstream analysis. The second trial proved more successful. A manual search for the species as listed on the UCNRS imperiled species list and their respective synonyms was run using R. A script for this downloading method was later written. The newly downloaded localities were combined to create the GBIF localities data. The advantage of the second method was more reliable localities, while the disadvantage was a loss of older localities.

3.4.2 Flora

Similarly to the other taxon, synonyms for the UCNRS rare flora species needed to be identified before downloading localities. Therefore a synonym data table was made that included the names listed in the UCNRS rare flora species list with their synonyms. Synonyms for the plant names were first acquired from the Jepson Interchange, CalFlora, and USDA Plants online database. Subsequently, synonyms from the CNPS Inventory of Rare, Threatened, and Endangered Plants of California were extracted. Lastly, Richard Moe from the University and Jepson Herbaria and Adam Wolf from Princeton University were personally contacted to assist in compiling synonymous names for each species. The synonym list was then sent to Richard Moe, who was able to query and download all corresponding localities from the Consortium of California Herbaria (CCH) database (CCH 2010). The localities from the CCH were used because the CCH is the most comprehensive database in California for vascular plant localities. One of the CCH's goals is providing accurate geographic information; hence there is an ongoing effort to georeference all possible localities. Currently, the database contains over 1.75 million vascular plant specimens submitted by twenty-six different institutions (CCH 2010).

3.5 Data clean up R

After obtaining our data from GBIF, R was used to refine the locality data. The cleanup was necessary to remove identifiably erroneous localities, in order to produce viable range maps. First, the data was trimmed to localities found only within the California state boundary, since that was the study area. Secondly, entries with geographic coordinates that differed from its county data was removed. We also eliminated duplicate species localities that occurred within a 1 kilometer by 1 kilometer cell, which gave the cells a weight of either one or zero. One indicates the species exists, while zero indicates the species is absence. Finally, we used two of the BioClim variables from WorldClim, mean annual precipitation and mean annual temperature, to eliminate outliers based on basic climatic differences. Any localities that differed more than three standard deviations from the mean were eliminated. The two climate variables were chosen because they are indicative of the climatic dataset used. The data cleanup reduced the possible error attributed to the locality data. Batrachoseps stebbinsi and Plethodon asupak were dropped due to this clean up.

3.6 MaxEnt

MaxEnt estimates a species geographical probability distribution given presence-only (Phillips, Anderson, Schapire 2006). . The GBIF localities were designated as the presence-only data and inputted along with 19 BioClim variables. California was set as the extent of our range, while the spatial resolution was set to that of the "WorldClim" data, which is 1-km^2. We used the 1-km^2 spatial resolution in order to capture environmental variability, particularly in areas of steep climatic gradients such as mountain (Hijmans, Cameron, Parra, Jones and Jarvis, 2005). The 19 bioclimatic variables represent annual trends, seasonality, and extreme or limiting environmental factors (Table 2).

MaxEnt requires two types of spatial data: the localities of species occurrences, which was taken from GBIF, and a representation of the environmental data across the study area. To produce the representation of environment data, MaxEnt was programmed to randomly sample 10,000 points to measure the environmental 'background' where each species occurs. Due to the size of the dataset as well as the number of species we dealt with, we decided to use the favorable default settings (Phillips and Dunik 2008). The process was automated by using the DISMO version 0.8-11 R package (Hijmanns et al. 2005).

The primary products from MaxEnt used in the study were the individual species distribution heatmaps. Each map illustrates a probability of occurrence across the state of California on a continuous scale from 0 to 1, where "0" signifies no statistical probability that the species occurs within the cell, and "1" indicates complete confidence the species occurs within the cell, according to climatic constraints and the currently known species localities. Additionally, range maps were produced by setting thresholds within MaxEnt through two objective approaches.

3.6.1 Thresholding

Specific thresholding is essential in order to transform species distribution results from environmental probability of suitability to the statistically relevant and more practical species presence/absence (Liu et al. 2005). The initial heat map conveyed a continuous suitability range, however, a threshold needed to be chosen to indicate the lowest accepted probability a species could occur. The many approaches that exist to determine the proper threshold fall within the subjective or objective category (Liu et al. 2005). Subjective approaches are characterized by the use of a fixed threshold level, such as 0.5 for all probability maps and treating all the species under one model, regardless of their differences. This approach has been noted to not only be arbitrary, but also lack any ecological basis (Osborne et al. 2001). Conversely, an objective approach seeks to maximize agreement between observed and predicted distributions for each species independently. A recent study aimed at exploring the benefits of different methods concluded that the objective approach increases the effectiveness of thresholding for species presence/absence over a subjective approach (Liu et al. 2005).

The two objective approaches used for thresholding were minimum probability and max SSS. Initially the minimum probability thresholding was employed, which produced a binary outcome based on the lowest probability where a locality was confirmed. The non-arbitrary value chosen was different for each species since the actual lowest probability depended on the confirmed individual GBIF locality record per species. After further review of the 30 possible maps by a leading expert in amphibians, Professor Brad Shaffer, only 18 of the threshold maps appeared to convey an accurate distribution for the particular species.

In order to improve the accuracy of the threshold maps produced, a second run was performed using max SSS thresholding. Maximizing the sum of sensitivity and specificity proves to be the superior method for thresholding when presence only data is available and reliable absence data is unavailable (Liu et al. 2013). Max *SSS* optimizes the trade off between a model's sensitivity, the proportion of observed occurrences correctly predicted, and specificity, the proportion of absence that are correctly predicted. In the context of the study, which does not use absence data, but the 10,000 background data, specificity refers to the proportion of background points correctly predicted. The yielded threshold maps appeared more viable as they are in accordance with known species ranges.

3.7 Spatial Analysis

3.7.1 Reserve Boundaries

The boundaries of each UCNRS reserve needed to be identified to in order to determine how many imperiled species exists on the UCNRS reserves, according to GBIF localities and MaxEnt species range predictions. The UCNRS provided a set of reserve boundaries in shapefile format. While analyzing the data however, there was some ambiguity in the reserve boundaries. At the time of the analysis, more updated reserve boundary shapefiles were made available, however of the forty-one possible boundaries, which included the thirty-eight reserves and three satellite reserves, only thirty-three were available. Of the thirty-three, seventeen were verified, indicating that the UCNRS spatial analysts confirmed the boundaries. Contrary, sixteen shapefiles were unverified and were still being reviewed and updated. The UCNRS is currently working to update all reserve shapefiles.

For a complete analysis, shapefiles were created for the eight missing boundaries. The shapefiles were created by using the geographic information listed on the UC NRS website and acreage data provided by the UCNRS (UCNRS 2013). The geographic information was geocoded using ArcMap 10.1 and a circular area around the point was produced that matched the total acreage data. Generally the geographic coordinate was utilized, however if it was unavailable, an address was used. The only reserve boundary that did not have any geographic information available was Old Women Mountain satellite reserve, and therefore was excluded. In total forty reserve boundaries were included in the analysis.

Initially the scope of the analysis was only to assess owned land, however after receiving the shapefiles from the UCNRS, all the boundaries were accepted for the analysis, in their current state. The produced shapefiles reflected total acreage. To note the discrepancies, the owned, use-by-agreement, and total acreage data was added to the shapefile attribute tables. The reserve boundaries were combined into one layer and exported for further processing.

3.7.2 GBIF Localities

ArcMap 10.1 was used to distinguish which amphibian GBIF localities exist within the UCNRS. The cleaned up amphibian localities, downloaded from GBIF, were first geocoded. The localities were then overlaid with the UCNRS boundaries and the localities found within the reserve boundaries were extracted. The tables from the amphibian localities subset were exported.

3.7.3 MaxEnt

Each amphibian species threshold maps were converted into shapefiles using DIVA GIS 7.0 and ArcMap 10.1. Once in shapefile format, the files were merged into one layer and overlaid with the UCNRS boundaries. The regions that intersected the MaxEnt maps and the UCNRS boundaries were extracted and their tables exported.

3.7.4 Suitability & Recommendations

The UC NRS recommendation map was generated in ArcMap 10.1 and based on two factors, ecoregion coverage and amphibian species richness. The Level III Ecoregions of North America shapefile (EPA 2012) was joined to the UC NRS reserve boundaries to produce the ecoregion coverage factor. The ecoregion coverage factor indicates the number of reserves that exist within each ecoregion. A score was embedded into the joined shapefile: the higher the number of reserves within the ecoregion, the lower the priority the UCNRS would have to place a reserve there, resulting in a lower score. The combined MaxEnt amphibian maps were converted into 3.29 cm by 3.29 cm pixels raster and each pixel was assigned a score. The pixels with the higher number of species found within it received a higher score. The two factor rasters were combined at equal weights to produce a total suitability score and the UCNRS recommendation map. The Ano Nuevo reserve was excluded from the suitability model because the island was absent from the ecoregion shapefile. Despite, the results remain the same because the Ano Nuevo Island already contains a reserve, and would not be a desirable place for a future reserve.

3.8 UCNRS Reserve Lists, GBIF Localities, & MaxEnt Threshold Maps Comparison

Correlation plots were produced to assess whether reserve lists were accurately listing species within each specific reserve in comparison to GBIF localities and MaxEnt threshold maps. Microsoft Excel. 12.1.0 was used to transform the raw data (Table 3) into correlation plots. The table is organized by species and records the number of reserves the species is found in according to the reserve lists, GBIF localities, and MaxEnt threshold maps. The UCNRS reserve lists by species were independently compared to the GBIF listed number of reserves and the MaxEnt listed number of reserves, resulting in two correlation plots (Figure 3, Figure 4). A one to one trendline was added to the charts to compare the relationships against a perfect correlation.

The data was then organized by reserve and the species count per reserve were recorded based on the UCNRS lists, the GBIF localities, and the MaxEnt predictions (Table 4). In addition, the ecoregions of each of the 38 reserves were identified for reference.

4 Results

According our criteria for designating imperiled species, California was found to have 2,617 at risk species: 2,152 flora, 93 mammals, 97 birds, 31 reptiles, 34 amphibian, 23 insects, and 26 fish species. The UCNRS reserve fauna species lists had 8,890 total entries (Appendix 1) and the UCNRS flora list has 10,126 entries (Haggerty & Mazer 2008). The UCNRS flora list entries exceed that of the fauna because the reserves already had an institutionalized flora list and flora speciation is higher than fauna. The UCNRS' unique flora species count was 3,300 (Haggerty & Mazer 2008). The query between the California Imperiled Species and UCNRS Species list showed that the UCNRS contained 13 imperiled amphibian species and 290 rare flora species. Only approximately 13% of the imperiled flora species in California were recorded by the UCNRS, compared to 43.3% for amphibians.

For the amphibian pilot run, there were a total of 4,522 downloaded GBIF species localities within California, 255 of which were located within UCNRS sites (Figure 5). The localities data provided evidence that 15 imperiled amphibian species were observed on the reserves. Spatial interpolation of the MaxEnt threshold maps predicted 27 of California's imperiled amphibians could have populations within the reserves. The three species that were not predicted on the reserves were *Bufo alvarius*, *Hydromantes shastae,* and *Rana yavapaiensis* (Table 3). *Ambystoma californiense, Ascaphus truei, Rana boylii, Rana draytonii, Rana muscosa, Rhyacotriton variegates, Spea hammondii,* and *Taricha torosa* were list by the UCNRS, recorded as GBIF localities, and predicted by MaxEnt. Comparatively, *Rana yavapaiensis*, *Hydromantes shastae*, and *Bufo alvarius* were not recorded in the UCNRS by any of the analyses. The remaining 18 amphibian species were recorded by a combination of two methods, either UCNRS listed and GBIF localities, UCNRS listed and MaxEnt predicted, or GBIF localities and MaxEnt predicted (Table 3). Given the different microhabitats across California, the amphibian localities varied greatly. The goal was to assess suitability of habitats for each amphibian species. Therefore each of the 38 reserves were placed into a California Ecoregion type. The reserves were located in 9 of the possible 13 ecoregions; the ecoregions with no reserve coverage are the Cascades, Klamath Mountains/ California High North Coast Range, Northern Basin and Range, and Eastern Cascades Slopes and Foothills (Table 4).

A positive correlation is seen between the unique species count based on the UCNRS list versus GBIF localities. The trend, however, does not follow a perfect correlation (Figure 3). For example, *Taricha torosa* was listed to inhabit 8 reserves, but GBIF only has localities for 4 reserves. A positive correlation is also seen between the unique species count based on the UCNRS list and the MaxEnt predicted species count per reserve (Figure 4). Again, the relationship did not follow the perfect correlation. For example, Rana draytonii, Rana pipiens, and Taricha torosa are predicted on 21 of the 38 reserves, where each of the species is listed by the UCNRS by less than 8 reserves. The other 27 species were predicted by MaxEnt represent a higher accuracy between the UCNRS reserve lists and the predictions of species ranges by MaxEnt.

The UCNRS future site recommendations were deduced from two factors: ecoregion coverage and species richness. The ecoregion suitability factor illustrates that the Coast Ranges in the west and the Sierra Nevada ecoregion in the east have the least reserve coverage (Figure 6a). The Southern California/ Northern Baja Coast ranges, also demonstrated an absence of reserves, indicating a higher priority for future reserve placements. The Mojave Basin and Range and parts of the Central California Valley contained the highest number of reserves, and therefore was ranked lower in considerations for a future reserve. The Northern California, Klamath Mountains/ California High Northern Coast Range, Cascades, Northern Basin and Range, and Eastern Cascades Slopes and Foothills all illustrated high amphibian species richness (Figure 6b). The Central California Valley depicted high species richness, however the Central California Foothills and Coastal Mountains, which surrounds the Central California Valley, exhibited among the lowest amphibian species richness. in nOrther The suitability model for future UCNRS sites suggests that the Southern California Mountain ecoregion in the southernmost area of California, the Klamath Mountains/ California High North Coast Range or Cascades ecoregion in the northernmost edge of California, and Coast Range near San Francisco Bay were most suitable (Figure 6c).

5 Discussion

Our results indicate that MaxEnt is over-predicting occurrence for some species at the UC NRS reserves, which is obvious from their range and threshold maps. For example, Rana draytonii is predicted to occur on 21 reserves by MaxEnt, but there are only 2 GBIF localities for it and only 2 reserves list it to occur. This can be seen in a positive way because it can encourage researchers and reserve visitors to seek for the particular species when originally it was not thought to exist at the reserve. It will hopefully push them to look harder. On the other side, it may be the case where a particular species of amphibian is predicted to occur based on climatic variables, but the other factors that MaxEnt does not account for (i.e. interspecies interactions) may in reality prevent the species from existing on the reserve.

Using the maximum sensitivity plus specificity approach is a more conservative approach to analyze the data. The main goal of this analysis is to find the relative correlation between what the reserves have listed by the NRS against the GBIF localities within the reserves or the MaxEnt predictions on the reserves. This is important because having specimens is the best way to demonstrate species presence. The relative correlation charts show the accuracy of species occurrences within the 38 reserves compared to the GBIF localities and MaxEnt predictions. The first correlation chart (Figure 3) compares GBIF localities within the 38 reserves and what the reserves have listed by the NRS. It indicates a positive correlation, however the data does not follow the 1:1 best possible correlation. Below the line, we see that reserves claim to have the species, however there are no records in GBIF. And above the line, we see that GBIF shows a locality but the reserve lists don't include the species. Since GBIF localities are based upon museum records, the inventory may be incomplete. The accuracy of the UCNRS lists compared to GBIF localities is weak, indicating that it is extremely important to update and maintain the accuracy of the reserve lists with specimen backed references and validation from the reserves.

In the second graph (Figure 4), we compared the correlation between the number of reserves where a species has been listed by the NRS and the number of reserves where MaxEnt predicted a species occurrence. Again, we included a 1:1 line that shows the best possible correlation. We found that the majority of the species were above the 1:1 line, which indicates that MaxEnt is predicting more occurrences than what the reserves list. The high points show that MaxEnt predicted two species on 21 of the reserves, while the UCNRS lists the species on less than two reserves. This indication shows that the species ranges cover a multitude of reserves within different Ecoregions although the reserves do not have the species. However, it implies that reserve directors should keep a lookout for these species in the future in case their ranges shift into the reserves. These species are labeled as "target species."

5.1 Challenges/Problems

During the analysis, we came across several challenges. The first challenge was acquiring up-to-date species lists from all the reserves. While many reserves were able to offer up some type of species list, they were often outdated or incomplete with missing taxon. Other reserves did not possess any type of species lists entirely. Therefore, all the lists submitted by the individual reserves were added into the UCNRS species list in their current state, which at times did not align temporally or taxonomically. We recommend each reserve have two lists- a list of supposed observations, and a list of predicted occurrences.

Another problem we dealt with was the synonymy issues. Out of the thirty amphibians processed, an overwhelming majority of them experienced name change(s) since 1966. The various types of name changes jeopardized the accuracy of locality data. To minimize the inaccurate data, an R script to clean up the data was applied.

The next issue was determining whether the analysis should be run on a species or subspecies level. The benefit of running the analysis on the species level was for uniformity and often times locality data at subspecies level is unreliable. The disadvantage of running all amphibians at species level was that the amphibians recognized at the subspecies level in the UCNRS imperiled species list, would have GBIF localities that belonged to other subspecies within the species it was searched as. The final decision was to run the analysis on either species or subspecies level, depending on the name listed in the UCNRS imperiled amphibian list.

Acquiring the shapefiles for the UC NRS boundaries was complicated because the data is still being updated. Therefore, the boundaries were used in an incomplete state and the additional boundaries created were fit to a circular area, which is not necessarily the shape of the reserves. The shapefile boundaries did not reflect uniform acreage data, some showed use-by-agreement acreage, while others showed owned or total acreage. The limited boundaries and varied acreage type representation introduced a degree of error into the spatial analysis.

Our last setback was choosing the thresholding method in MaxEnt. Since MaxEnt is heavily reliant on locality data, the accuracy of the locality data was crucial in producing a reliable predicted species range map. While we tested both the minimum probability and max SSS approach, the max SSS approach appeared to be more realistic in comparison to the species natural expected ranges. All the MaxEnt distribution maps showed the correct range shapes, therefore the deviation in the threshold maps may be attributed to introduced species localities.

Although our challenges did produce a margin of error, many of the issues were beyond our control. By working through the problems we were able to refine our methodology correct for most of the issues and provide the most accurate results we found possible.

5.2 Recommendations/Suggestions

We recommend the UCNRS update current species list and make them available to the public. More specifically, we recommend that these list be more accurate and properly named/listed. We also recommend that these list be digitized and displayed on the UCNRS website so that these lists can be accessible by the public and better able to assist research efforts. The digitization of species lists will give a centralized location where researchers, faculty and students alike can easily utilize these lists. The accessibility of species lists is important to facilitate research and to ensure that the UCNRS is living up to its statement of purpose and conserving imperiled species. For example, a comprehensive species list will enable researchers to choose a specific reserve they should work on given a particular species they are interested in. By having current and more updated species lists researchers can effectively conduct research, whereas if these species list were outdated, the species of interest might not be present there.

Moreover, We chose the future UCNRS site recommendations by identifying California's 13 ecoregions and identifying areas of species richness. Future UCNRS sites are areas where the UC system has a few reserves and where there is vast species richness of imperiled species. These two parameters show potential UC reserve areas that would be instrumental for the conservation of imperiled species. Additionally, it is important to have accurate shapefiles available for researchers in case they want to conduct research dealing with programs like GIS and spatial analysis. Lastly, following our recommendations will allow for a more system-wide approach to the UCNRS and ignite the movement towards a more collaborative environment in the University of California.

5.3 Future Work

The future of the research should expand to other taxonomic groups to produce a more holistic assessment of the UCNRS's success in protecting California's imperiled species. Due to time constraints, only the amphibian taxon was completely assessed. Since a protocol was designed, the remaining taxon should be studied. Eventually the results from each taxon analysis should be combined to produce an overall assessment on whether UCNRS is accomplishing its goal to protect California's at risk species. Furthermore, fieldwork for collecting species localities should be done to confirm the predictions made and validate the modeling techniques used.

Lastly, considering progressing effects of climate change, future climate models should be utilized to advance the MaxEnt modelling parameters. The climate models may better inform which areas are most suitable for a new reserves, since they would reflect the future climate distribution. Additionally, the future climate models could be used to assess the success of the UCNRS in protecting its imperiled species from the long-term effects of climate change.

6 Conclusions

With respect to amphibians, the UCNRS is successful in protecting endangered, threatened, and special concern species. For the small amount of land it has and the date it was founded, it is able to cover a surprising amount of different ecoregions. However, it does not cover them all. The central valley and coastal redwoods need more coverage. Many of these species have very small, specific ranges. In these cases, it is often not feasible for the NRS to obtain land that would cover these species as it is not readily available. The same can be said for some of the ecoregions that lack coverage also. The lists we compiled or synthesized show some interesting discrepancies. First, the GBIF localities and the UCNRS lists tended to disagree with each other. This shows that the UCNRS lists need to be updated. The MaxEnt lists showed much more occurrences than either of the other lists, and we think that it greatly over predicted species occurrence. However, this may not be a bad thing as it can lead to researchers looking harder for species of interest in the UCNRS and refining the sites' species occurrence lists.

7 Acknowledgements

Brian Haggerty & Susan Mazer for compiling the 2008 UC NRS flora list. The UCNRS spatial analysts for providing the UC NRS reserve boundaries shapefiles and working to update them. Adam Wolf from Princeton University for helping sort out the flora synonym issues. Richard Moe from the Jepson Herbaria for helping with flora synonym issues and downloading all the California Consortium of Herbaria localities data. Amber Wright for developing the protocols and R scripts for downloading GBIF localities and producing MaxEnt products, as well as troubleshooting R issues. Erin Riordan for providing constant support and professional advice with the direction of the study, as well as troubleshooting the MaxEnt process. The UCNRS and Peggy Fiedler for providing funding and support for this entire study. The UCLA Institute of the Environment and Sustainability for providing students with this unique opportunity to experience working in a close knit group along leaders in the field of environmental studies. Lastly, the distinguished professor Brad Shaffer, director of the UCLA La Kretz Center for California Conservation Science, without whom none of this study would have been possible.

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9 Figures & Tables

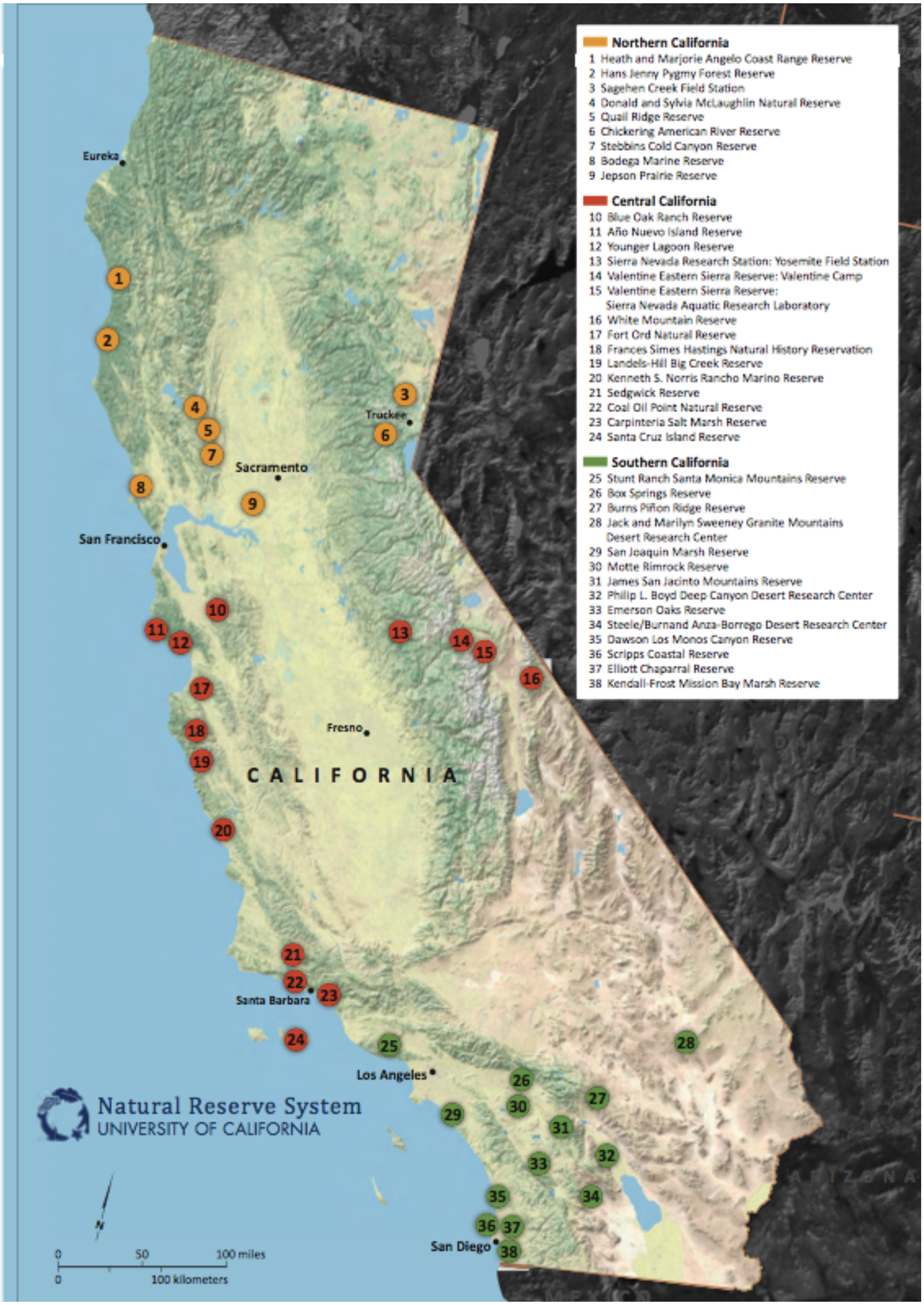

Figure 1: A map of the 38 University of California Natural Reserve System sites. (Fiedler et al. 2013)

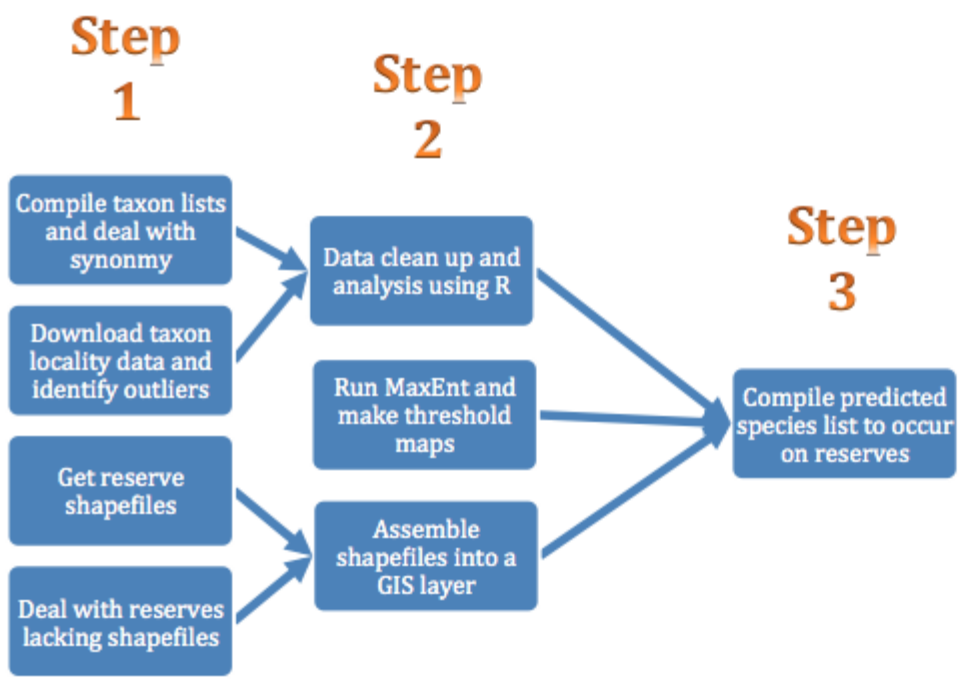

Figure 2: A workflow that introduces the pipeline starting from raw data and proceeding to the final goal of recommendations of new reserves within the UCNRS.

Table 1: Coverage of each taxon given the State and Federal lists of endangered and threatened animals in California.

List	Plants	Insects	Vertebrates
Federal Endangered Species Act: Endangered and Threatened Wildlife and Plants List	+	+	+
California Endangered Species Act: Rare, Threatened, and Endangered Species List	+	+	+
California's Species of Special Concern	-	-	+
California Native Plant Society: California's Rare Plant Inventory	+	-	-

Table 2: BioClim variables used by MaxEnt in order to produce species distribution maps.

BIO1 = Annual Mean Temperature

BIO2 = Mean Diurnal Range (Mean of monthly (max temp - min temp))
BIO3 = Isothermality (BIO2/BIO7) (* 100)
BIO4 = Temperature Seasonality (standard deviation *100)
BIO5 = Max Temperature of Warmest Month
BIO6 = Min Temperature of Coldest Month
BIO7 = Temperature Annual Range (BIO5-BIO6)
BIO8 = Mean Temperature of Wettest Quarter
BIO9 = Mean Temperature of Driest Quarter
BIO10 = Mean Temperature of Warmest Quarter
BIO11 = Mean Temperature of Coldest Quarter
BIO12 = Annual Precipitation
BIO13 = Precipitation of Wettest Month
BIO14 = Precipitation of Driest Month
BIO15 = Precipitation Seasonality (Coefficient of Variation)
BIO16 = Precipitation of Wettest Quarter
BIO17 = Precipitation of Driest Quarter
BIO18 = Precipitation of Warmest Quarter
BIO19 = Precipitation of Coldest Quarter

Table 3: Amphibian species localities given UCNRS lists, GBIF localities, and MaxEnt predictions.

Species	Number of Reserves (UCNRS)	Number of Reserves (GBIF)	Number of Reserves (MaxEnt)
Ambystoma californiense	3	3	7
Ambystoma macrodactylum croceum	0	0	4

Ambystoma macrodactylum sigallatum	0	0	4
Anaxyrus californicus	0	0	12
Aneides flavipunctatus niger	0	0	2
Ascaphus truei	1	1	3
Batrachoseps aridus	0	1	5
Batrachoseps campi	0	1	1
Batrachoseps minor	0	0	1
Batrachoseps simatus	0	0	1
Bufo alvarius	0	0	0
Bufo canorus	0	2	5
Bufo exsul	0	1	1
Dicamptodon ensatus	2	0	7
Hydromantes brunus	0	1	1
Hydromantes shastae	0	0	0
Plethodon stormi	0	0	1
Rana boylii	4	5	14
Rana cascadae	0	0	1
Rana draytonii	2	2	21
Rana muscosa	3	2	9
Rana pipiens	0	1	21
Rana pretiosa	0	0	6
Rana sierrae	0	4	6
Rana yavapaiensis	0	0	0
Rhyacotriton	1	1	2

variegatus			
Scaphiopus couchii	0	0	2
Spea hammondii	2	1	16
Taricha rivularis	1	0	4
Taricha torosa	8	4	21

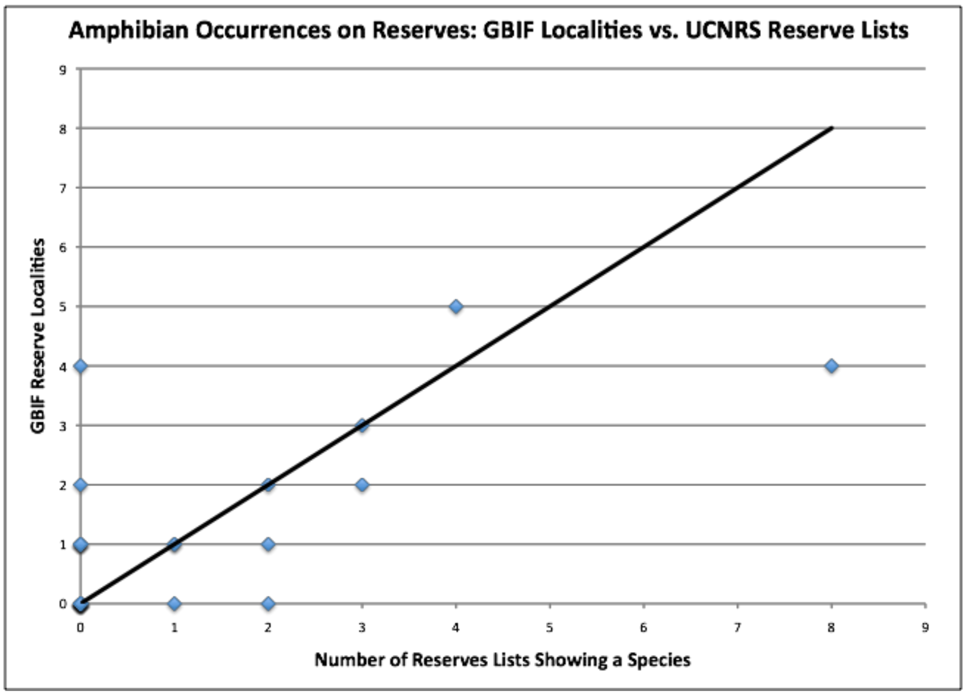

Figure 3: Testing the accuracy of the current UCNRS lists compared to the GBIF localities found and recorded within the reserves produced a relatively low correlation. The absence of correlation is seen by the comparison of the 1:1 ratio line of the species localities. Each dot

represents one of the 30 imperiled amphibian species.

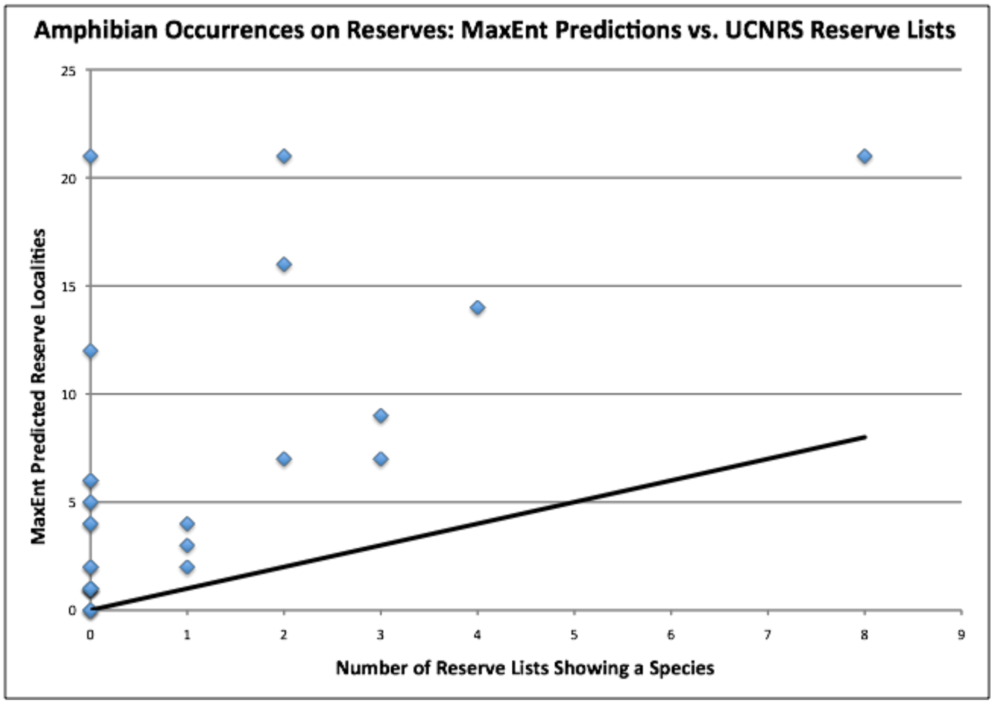

Figure 4: Further testing the accuracy of the reserves, the correlation between the current UCNRS reserve lists and the MaxEnt predictions shows what species might appear in the reserves when the climate changes in the future. Each species is represented by a dot and a 1:1 ratio line shows a low correlation.

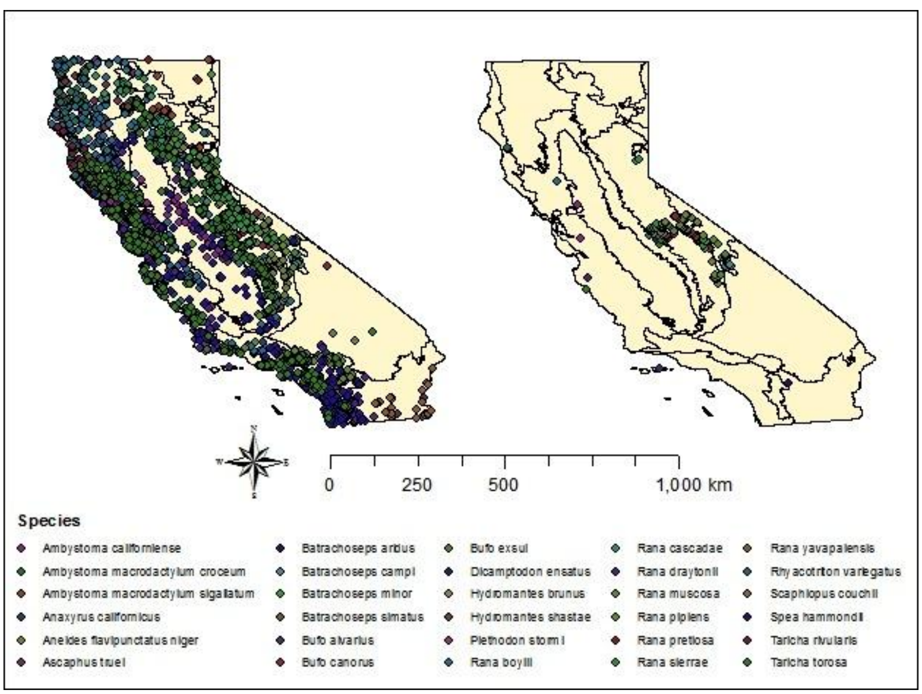

Figure 5: There were 4,522 amphibian localities found in GBIF in the state of California, seen on the left. 255 of those localities were found within the 38 UCNRS reserves, seen on the right.

Table 4 : The UCNRS reserve list given their ecoregions and listed endangered, threatened, and species of special concern of Amphibian species.

Reserve	California Ecoregions	Number of Imperiled Species (UCNRS Lists)	Number of Imperiled Species (GBIF)	Number of Imperiled Species (MaxEnt)
Año Nuevo	Coast Range	0	0	0
Angelo Coast Range Reserve	Coast Range	5	3	4
Anza-Borrego Desert Research Center	Sonoran Basin and Range	0	0	2
Blue Oak Ranch Reserve	Central California Foothills and Coastal Mountains	4	1	5
Bodega Marine Reserve	Coast Range	0	0	6
Box Springs Reserve	Southern California/Northern Baja Coast	0	0	7
Boyd Deep Canyon Desert Research Center	Sonoran Basin and Range	1	1	4
Burns Piñon Ridge Reserve	Mojave Basin and Range	0	0	2
Carpinteria Salt Marsh Reserve	Southern California/Northern Baja Coast	0	0	3
Chickering American River Reserve	Sierra Nevada	0	0	5

Coal Oil Point Natural Reserve	Southern California/Northern Baja Coast	0	0	3
Dawson Los Monos Canyon Reserve	Southern California/Northern Baja Coast	2	0	5
Elliott Chaparral Reserve	Southern California/Northern Baja Coast	2	0	5
Emerson Oaks Reserve	Southern California Mountains, Southern California/Northern Baja Coast	0	0	5
Fort Ord Natural Reserve	Central California Foothills and Coastal Mountains	1	0	3
Hastings Natural History Reservation	Central California Foothills and Coastal Mountains	1	4	5
James San Jacinto Mountains Reserve	Southern California Mountains	1	0	4
Jenny	Coast Range	0	0	5
Jepson Prairie Reserve	Central California Valley	0	1	1
Kendall-Frost Mission Bay Marsh Reserve	Southern California/Northern Baja Coast	0	0	3
Kenneth S Norris Reserve	Central California	0	0	3

	Foothills and Coastal Mountains			
Landels-Hill Big Creek Reserve	Central California Foothills and Coastal Mountains	1	1	6
McLaughlin Natural Reserve	Central California Foothills and Coastal Mountains	2	2	3
Motte Rimrock Reserve	Southern California/Northern Baja Coast	1	0	5
Oasis de los Osos	Sonoran Basin and Range	0	0	5
Quail Ridge Reserve	Central California Foothills and Coastal Mountains	5	0	4
Sacramento Mountains (satellite of Sweeney)	Mojave Basin and Range	0	0	0
Sagehen Creek Field Station	Sierra Nevada	3	1	7
San Joaquin Freshwater Marsh Reserve	Southern California/Northern Baja Coast	0	0	4
Santa Cruz Island Reserve	Southern California/Northern Baja Coast	0	1	6
Scripps Coastal Reserve	Southern California/Northern Baja Coast	0	0	3

Sedgwick Reserve	Central California Foothills and Coastal Mountains	2	0	5
Stebbins Cold Canyon Reserve	Central California Foothills and Coastal Mountains	2	0	4
Stunt Ranch Santa Monica Mountains Reserve	Southern California/Northern Baja Coast	1	0	4
Sweeney Granite Mountains Desert Research Center	Mojave Basin and Range	0	0	0
Valentine Eastern Sierra Reserve	Sierra Nevada	0	1	5
Valentine Eastern Sierra Reserve - SNARL	Central Basin and Range	0	0	4
White Mountain Research Center	Central Basin and Range, Mojave Basin and Range, Sierra Nevada	0	7	12
Yosemite Field Station	Central California Foothills and Coastal Mountains, Sierra Nevada	0	7	11
Younger Lagoon Reserve	Central California Foothills and	2	0	7

	Coastal Mountains			

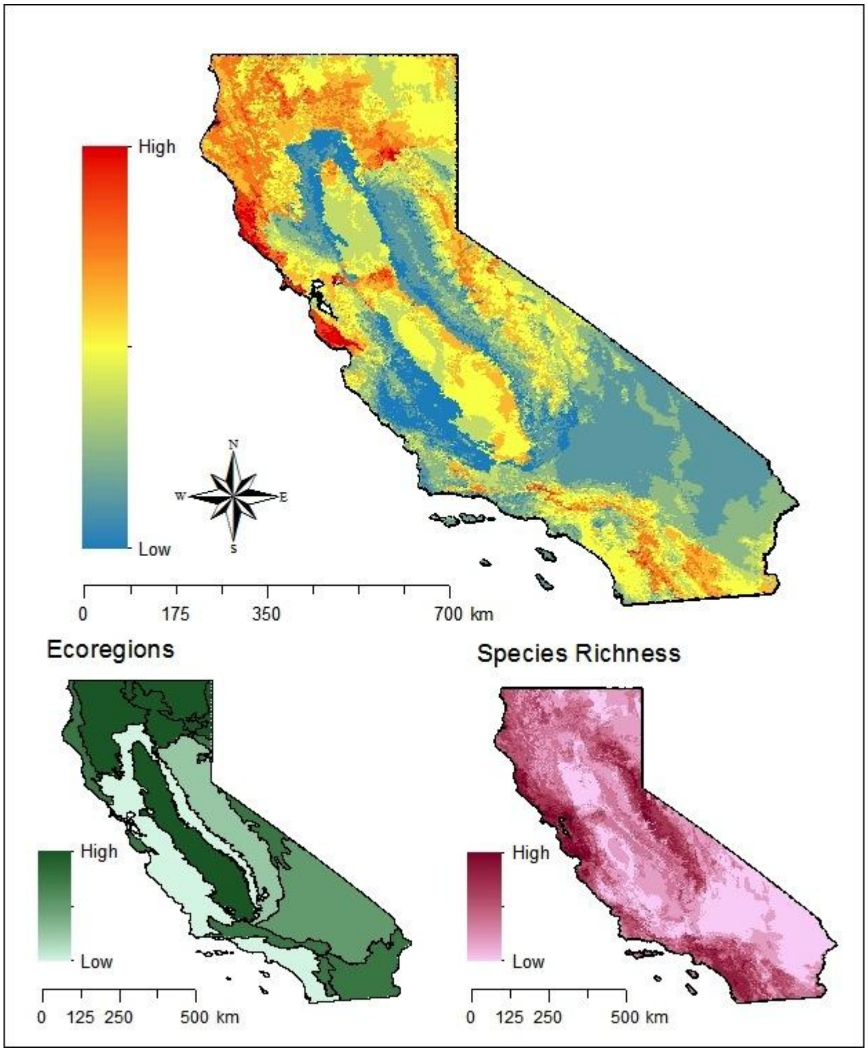

Figure 6 a,b,c. Figure 6(a) shows the ecoregions within the state of California and the scale represents a high or low occurrence of reserves with each of the 13 ecoregions. Figure 6(b) includes with species richness, or biodiversity, across California and the scale represents a high or low number of species per given area. Figure 6(c) is a heat map due to the combination of the ecoregions map (a) and the species richness (b). The recommendations set are highest in areas with high species diversity in areas that lack reserves in specific ecoregions.

10 Appendix *(Electronic)*

1. California Endangered List (Appendix 1)

a. UCNRS Species List (Systemwide)
b. UCNRS Endangered Species List (Systemwide)
    i. Categorized by taxa

    ii. Synonym list
c. California Endangered Species List
d. GBIF lists Amphibian
e. MaxEnt 3 maps for each, put on 1 page
    i. heat map w/ coordinates
    ii. threshold minimum
    iii. threshold sensi+speci
f. Excel
    i. ArcGIS Produced Tables
        1. GBIF- matches
        2. GBIF- species count in reserves
        3. MaxEnt- matches
        4. MaxEnt- species count in reserves
        5. MaxEnt- reserve count in species range
g. Ecoregion & UCNRS Site overlay