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Wildfire Exposure To Critical Habitat Of Endangered And Threatened Species In California

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This Master's Project

WILDFIRE EXPOSURE TO CRITICAL HABITAT OF ENDANGERED AND THREATENED SPECIES IN CALIFORNIA

by

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Table of Contents

List of Tables

List of Figures

Acronyms

Abbreviation Code	Definition
BIA	Bureau of Indian Affairs
BLM	Bureau of Land Management
CAL FIRE	California Department of Forestry and Fire Protection
CBD	Center for Biological Diversity
CITES	The Convention on International Trade in Endangered Species of Wild Fauna and Flora
CWHR	California Wildlife Habitat Relationships
ECOS	Environmental Conservation Online System
ES	Endangered Species
ESRI	Environmental Systems Research Institute
GIS	Geographic Information System
NMFS	National Maine Fisheries Service
NPS	National Park Service
TESS	Threatened and Endangered Species System
TS	Threatened Species
USESA	United States Endangered Species Act
USFS	United States Forest Service
USFWS	United States Fish and Wildlife Service
USGS	United States Geographic Survey
WUI	Wildland-Urban Interface

Abstract

Researchers, fire ecologists and wildlife managers are concerned about impact to endangered and threatened species and their critical habitat due to the projected increase in future wildfires. Wildfires have been studied in California for the last six decades and have been increasing at an alarming rate since the 1980's. In this study, I use the 2018 spatial dataset for critical habitat of federally endangered and threatened species located in the state boundaries of California and compare it to a spatial dataset for wildfires that have occurred over the span of 32 years (1984 to 2016). Trends are derived from spatial data by using ArcGIS and Tableau software. A macroscale analysis was conducted to determine what species types are most sensitive to wildfire encroachment. Then I conducted a microscale to determine which specific endangered and threatened species are threatened by wildfire to determine which recovery plans should be reviewed. Analyses indicted that critical habitat for amphibian, bird and insect endangered or threatened species types are most sensitive to wildfire encroachment. Five specific species that are more impacted than others: Arroyo southwestern toad, California red-legged frog, California condor, coastal California gnatcatcher, and Quino checkerspot butterfly. Life traits were researched for these species and recovery plans were examined for wildfire mitigation strategies. Modifications were made based on these considerations and life traits. Results and future recommendations include specific recovery plan updates that should include wildfire mitigation strategies, research on wildfire impacts on these species, and ideas with regards to how this data can be used in the best interest of the species, ecosystem, and wildlife managers.

Introduction

With wildfires on the rise throughout the United States, managers are concerned about the impact on critical habitat for endangered (ES) and threatened (TS) species found under the United States Endangered Species Act (USESA). Wildfires have increased in size, number, intensity and severity for decades throughout the United States (Barrett et al. 1997, Jain et al. 2004). Currently in California, the average annual area burned and quantity of wildfires that are more than 1000 acres in size have more than doubled since the 1980's (State Board of Forestry and Fire Protection 2018). These metrics are estimated to continue to keep rising in the future based on current predictions (van Wagtendonk et al. 2018). Wildfires often impact safe havens in wildlife refugia to vulnerable species that are endangered or close to extinction (Guo et al. 2017, Kolden et al. 2017). However, there has yet to be a widely available direct spatial comparison of critical habitat for ES and TS found under the USESA and historical wildfire data. This is likely due to confusing decision making for when to add species to the USESA and the complexity of wildfire ecology in ecosystems throughout California (Martin et al. 2017, van Wagtendonk et al. 2018). Regardless, a spatial analysis could give insight in respect to critical habitats for ES and TS that could be impacted in the future, and how recovery plans for ES and TS can be adjusted to account for this impending increase in wildfire activity in California.

An increase in wildfire attributes is partially due to factors pertaining to past changes in fire regimes due to complete fire suppression, changes in land use, and vegetation types. Fire regimes changed a considerable amount in the early 20th century due to policy changes surrounding complete wildfire suppression (van Wagtendonk 2007). These changes in policy have created California's vegetation to be poorly maintained and ecosystems have been made vulnerable to disease and pests (Commission on California State Government Organization and Economy 2018). Research shows that there is also a projected increase in lightning strikes and warmer weather due to climate change in the future (Romps et al. 2014). Global warming is expected to create warmer temperatures and earlier snowmelt, causing soil and vegetation to be drier than normal during late wildfire season (Westerling et al. 2006). A lack of soil moisture and precipitation has been forecasted to increase wildfire severity during fire season (Westerling et al. 2003). Increasing area, quantity and severity in wildfires have been seen in ecosystems found throughout California that contain vegetation. This includes northern forested areas in Klamath National Park, grassland ecosystems in the San Joaquin Valley, riparian and coastal areas found in southern California, and high desert areas found in eastern California (Westerling et al. 2006, Cheney et al. 1998, Bendix et al. 2017, Zedler et al. 1983, Brooks 2002). The human population is expected to continue to increase in the future as well, and data shows that the wildland-urban interface (WUI) is linked to an increase in wildfires (Syphard et al. 2007).

ES and TS found under the USESA can also be found in a variety of ecosystem. California contains 85 million acres of land classified as wildlands, which make up commercially, privately and government-owned areas (CAL FIRE 2012). These wildlands provide critical habitat for over 100 federally ES and TS protected under the USESA, which is a law to help conserve ecosystems where ES and TS are housed to prevent species extinction (Williams 1973). Not only do ES and TS play an active role in valuable ecosystem services for humans, but species extinction and a lack of biodiversity can also cause ecological disasters that lead to more extinction (Pimm et al. 2014, Srinivasan et al. 2007).

In order for a species to be considered protected under the USESA, the United States Fish and Wildlife Service (USFWS) and National Marine Fisheries Service (NMFS) are required to produce a recovery plan and designate an area for their recovery. This recovery plan outlines goals, management practices and timelines to predict how long it would take to get the endangered species back to recovered population values. A protected spatial area is also established, also known as critical habitat, in order to estimate where and how much area the ES or TS would need to rebound in population (USFWS 2011). Recovery plans will sometimes include wildfire protection or wildfire mitigation strategies that help best protect the species. Although recovery plans and critical habitat are helpful and thoroughly put together, they are not always regularly updated with the most up to date science because of costly analysis and long congressional litigation or court proceedings (Taylor et al. 2005). They are also sometimes neglected to be made completely due to a lack of funds and time.

This paper evaluates federally ES and TS types by groups and individual species that are most vulnerable to increasing wildfire encroachment in necessary critical habitat in California.

Recovery plan examination helped determine how current federal recovery plans can be changed in the future to mitigate these increasing future wildfires. A Geographical Information System (GIS) analysis using Environmental Systems Research Institute (ESRI) software was performed. Spatial datasets were used to compare critical habitat for each ES and TS type (USFWS 2018) to wildfire encroached areas in California from 1984 to 2016 (Eidenshink et al. 2007). Analysis on a macroscale was performed to determine what species types are most sensitive to wildfire encroachment. To further this analysis, I performed a microscale analysis to determine which specific ES and TS critical habitat is most threatened by wildfire encroachment. For each critical habitat that was heavily impacted by wildfire, a literature search was performed for each ES or TS to determine the biology and physical habitat needed in order to define the best method of fire suppression and mitigation. Finally, recovery plans for each heavily impacted species was reviewed to determine if any type of fire mitigation strategies are being utilized in the current methods of the species management. By performing this GIS analysis and thoroughly examining recovery plans for specific ES and TS, I provide recommended updates to current recovery plans for California's species found under the USESA to prepare for increased wildfires that are predicted to occur in the future.

Methods

I. GIS Datasets

I used several datasets to conduct my macro and micro analysis (Table 1). A shapefile was used to define the entire state of California as a boundary. This boundary file was sourced by the United States Census Bureau website and contains the boundaries of each state found in the United States. It includes one shapefile in polygon form for the entire United States, while attributes are divided by state names and areas. This file was used to prepare the critical habitat for ES or TS. The shapefile was set to decimal degrees and the geographical coordinate system was downloaded as GCS_North_American_1983 with D_North_American_1983 Datum.

The federal ES and TS critical habitat dataset were sourced by the Data.gov website via the US Department of the Interior, the USFWS, and the Environmental Conservation Online System (ECOS). This dataset consisted of critical habitat for 688 out of the total 1634 ES and TS found throughout the United States and was recorded in 2018. Attributes include common names, scientific names, and species codes given by the Threatened and Endangered Species System (TESS) created by the United States Geographic System (USGS) which can be seen in Table 2. Spatial data were downloaded as shapefiles in polygon form. These spatial files are intended to show where ES and TS are expected to live and successfully increase in population size during the recovery process. These polygons were clipped using the state of California shapefile in order to determine where ES or TS are located in California. There are 14 types of species found within California according to TESS. Critical habitat spatial data found within California included 9 out of the 14 total species types found in California within the TESS system. Critical habitat spatial data were not available for all 14 species types, nor was it available for every species found in each type. This is due to a lack of available resources and funding that go to the USESA. Data were set to decimal degrees and the geographical coordinate system was downloaded as GCS_WGS_1984 with D_WGS_1984 Datum.

Wildfire raster data were obtained from the Monitoring Trends in Burn Severity (MTBS) website (Eidenshrink et al. 2007). This data is a collection of major wildfires that have happened each year since 1984 to 2016. Wildfires in this analysis include all fires burning to 1000 acres or greater and is dissected through an institutionalized and steady system, creating pixels at a 30-meter resolution. Burn severity interpretation is ranked in values from 1 to 6, with each value being resembled by a different color:

- 1 or Dark Green resembles unburned (not used in this project)
- 2 or Light Blue resembles low severity burned areas
- 3 or Yellow resembles moderate severity burned areas
- 4 or Red resembles high severity burned areas
- 5 or Bright Green resembles increased greenery areas compared to previous years (not used in this project)
- 6 or White resembles bodies of clouds or shadows (not used in this project)

This data is set to linear units of meters and the XY coordinate system used was Albers_Conical_Equal_Area with D_North_America_1983 Datum.

II. GIS Macro Analysis

For this GIS macro analysis, I changed the projection of all datasets to keep consistency throughout the project. The shapefile for the state of California was selected using the "Select by Attribute" tool. Boundary data was exported for downstream analysis. Critical habitat shapefiles for ES and TS were clipped using the California state boundary in order to use only ES and TS critical habitat found within California. This gave a total of 115 ES and TS spatial datasets Three of the ES and TS in this list had spatial datasets that were broken up between regions. These datasets were added together, making a total of 112 ES and TS critical habitat spatial datasets. A field was added in the attribute table to determine what the species code meant according to TESS (Table 2). Wildfire raster data by year was obtained and an attribute table was built for each dataset using the "Build Raster Attribute Table" and was kept for downstream analysis. Shapefiles for ES and TS critical habitat were given a geometry field in the attribute table for area. Each polygon was grouped and dissolved according to TESS code. Groupings were split into separate shapefiles by using the "Split by Feature Class" tool.

MTBS raster data were used as a classifier and the new ES and TS critical habitat shapefiles were used as the habitat in order to use the "Tabulate Area" tool for every year in each TESS species grouping. This was done using an iterator in a model. A field was added as well to produce the area in meters squared for all wildfires found in the habitat for each species grouping. Total area in meters squared for total ES and TS critical habitat was also added. The files produced in this model were dbf files. All of these files were merged using another model, with the year and species grouping being added to depict which year the data came from.

Finally, dbf files were exported into an excel file. Each wildfire category (low, moderate, high) found in critical habitat for ES and TS grouping was normalized using the total amount of ES and TS critical habitat found in the state of California for each species group. The data was then graphed and analyzed using Tableau software to show trends needed for further analysis.

III. GIS Micro Analysis and Species Selection

Using the results of the macro analysis, I examined further using the three most impacted species groups. ES and TS groups most impacted by wildfire encroachment were defined and ungrouped to determine five ES and TS individual species impacted most by wildfire inundation.

Literature searches to determine biological, physiological, and life traits for these five species were done to determine how fire can impact their biology and to define the best methods for wildfire management strategies. Informative information was found on the federally funded Environmental Conservation Online System, or ECOS, website (US Fish and Wildlife Service 2018), the California state funded California Wildlife Habitat Relationships, or CWHR, website (California Department of Fish and Wildlife 2018), and the Center for Biological Diversity, or CBD, website (Center for Biodiversity 2019).

IV. Recovery Plan Comparison

Federal recovery plans for the five most impacted ES and TS were reviewed and compared with information relating to documentation found in the previous literature search. The most recent recovery plans were used to determine what kind of management plan is being exercised and if it includes any type of wildfire inundation and wildfire mitigation techniques. Federal grey literature was also researched to determine what is currently being done to help determine what can be added to recovery plans that helps document what else can be done to learn more about the species and how wildfire impacts them.

Background

I. Fire Regimes

Changes in fire regimes have made a large impact on why there has been an increase in wildfires. Fire regimes are complex fire patterns driven by fuels, topography, and weather (van Wagtendonk et al. 2018). All ecosystems being made up of different vegetation, landscapes, and climate mean that each area is characterized by a different fire regime and a different time interval between when fires happen. They are structured by natural characteristics related to the ecosystem, climate and human impact. Land slope, elevation, and accumulation of wildfire ignition are all ecological factors that play an important role in how fire patterns are initially defined (Taylor et al. 2003). The kinds of vegetation, height of vegetation, and time of season can also play a role in how fire regimes are originally structured. Past fuel management in the ecosystem, changing weather patterns, and the introduction of invasive plants (Morgan et al. 2001) are all modifications that can act in changing fire regimes and cause original patterns to shift. Humans can complicate fire regimes with manmade structures that can easily catch on fire. Concurrently, humans as a population create a uniquely unpredictable environment because of the easy accessibility to fire. People accidentally or purposefully start fires that can quickly become out of control in the perfect wind storm. These features are always evolving, making fire regimes dynamic and often changing.

The species type and size of vegetation found in an ecosystem is one of the most influential factors for how fire regimes advance. Surface fires are defined as wildfires that spread in the understory or low-lying layer of an ecosystem (Pausas et al. 2014). This can be grasslands, deserts, and savannas. They usually occur at higher frequencies and at a lower intensity. However, crown fires are characterized as fires that impact all vegetation in an ecosystem (Pausas et al. 2014). Examples of these kinds of fires include wildfires that start in chaparral or shrubland and closed-cone pine forests. Crown fires usually occur at a higher intensity. Examples of each type of fire are not limited to the specific ecosystems stated and can occur in other ecosystems if given the appropriate circumstantial conditions. For example, newer and healthy tree stands in less dry conditions can undergo a surface fire with no impact to the top layer of the tree stands.

Ecosystems are sensitive to wildfires and how often they occur. In some habitats throughout California and beyond, fires can implement rejuvenating qualities that produce healthier and more efficient ecosystems. A common example of this are evolutionary traits acquired by plants in historically fire prone areas (Rowe 1983). Some plant types, known as endurers, re-sprout a new shoot or dormant bud upon encroachment of wildfires, while other plant types, known as evaders, generate a fire-resistant bank in the top layer of soil that relies on fires to germinate. Invaders are short lived and are early arrivers in the season, causing a large abundance of them by the time fire season normally starts. Resisters are plant species that are resistant to fires at the adult stage due to specific phenotypic traits, such as thick bark and a lack of ladder fuel. Finally, there are avoiders, which are sometimes argued to not be a direct adaptation to fire. These are plant types that arrive late in the season. It is clear that some plant species heavily rely on wildfires for propagation. Because of this reason, it can appear that some plant species follow the spread of wildfires.

Simultaneously, plants are also known to live their life cycle based on the number of fire intervals that happen over a certain amount of time (Pausas et al. 2014). Some plants cannot live past one fire interval, while others can live through several fire intervals. Although most examples of fire facilitating species are plant species, animal species can also have a symbiotic relationship with these fire dependent plants, and therefore can also be positively impacted by fire regimes. This usually happens over long periods of times to species that undergo an increase of selective pressure in a very specific habitat (Moran 2006). For example, some insects will sometimes use plants for shelter and feeding that are reliant on fires in some way.

Despite some plants and ecosystems being highly evolved to utilize wildfires throughout time, other ecosystems that have either very long fire regimes or too many wildfires in too short of time can suffer. The impact of wildfires in areas that are not historically prone to fire can drastically change the distribution and abundance of some plant types (McKenzie et al. 2004). These fire intolerant plants can sometimes disappear from an ecosystem entirely after a wildfire. Damage to soil has also been recorded in some ecosystems (Certini 2005). Nutrients become depleted in the soil and cannot be replenished fast enough for the plants to successfully thrive. In addition, animals and insects that once relied on these plants for food and shelter are ultimately pushed to find an alternative support system.

Plants clearly play a major role in how fire regimes are shaped throughout California's numerous ecosystems. Hence, it would not be a surprise to detect changes in fire regimes when new plant species are introduced to formerly unstable habitats. Humans and animals often times act as accidental transportation for invasive plant species through seeds or plant clippings attached to skin, fur, clothing, or shoe apparel. This spreads by way of migration patterns, hiking trails, camping, or outdoor sporting events. Remnant plant parts that get tracked in to sensitive ecosystems near susceptible areas can be disastrous if followed by a wildfire. If a fire occurs in an area full of fire intolerant plant species, an invasive fire facultative plant could take over the habitat that was once used by native species (Brooks et al. 2004). Ecosystem services can take a negative toll when this occurs, while animal species can also suffer. Wildfire ecologists are often mindful of this topic and restoration efforts recurrently attempt to attack this ongoing problem before it gets out of control by performing invasive removal projects.

II. Past Wildfires in California and the United States

Historically, wildfires and fire regimes were once much different in California. Habitats were not deconstructed or changed because of land use purposes, invasive plants were much less likely to be tracked into sensitive habitat, and there was less human development and structural settlements. In "A Summary of Fire Frequency Estimates for California Vegetation before Euro-American Settlement", the author (van de Water et al. 2011) estimates what fire intervals were prior to Euro-American settlements moving into California. This was done by performing an exhaustive review of published and unpublished literature and consulting with 28 fire ecology experts. Data was recorded for vegetation found in the area and mean, median, minimum and maximum fire returns in years prior to the mid 19th century. Averages were taken of all metrics in order to consider a more simplified result. Averages range to as low as 11 years in habitats containing yellow pine species and dry mixed conifer species, while habitats containing desert mixed shrub species had an average fire interval of 610 years. While reviewing this literature, van de Water clearly shows that these fire interval estimates are extremely variable, therefore finding the average of several pieces of literature was critical in this reference.

Although these differences in fire regimes stem from several reasons, policy changes throughout history play a major role for the differences seen. From 1872 to 1967, it was thought best to completely suppress any wildfire that might start in fear of the fire becoming out of control (van Wagtendonk 2007). In fact, US Forest Service (USFS) was established in 1905 and complete fire suppression was its main objective. That may have seemed like a great idea at the time due to the lack of modern technology used to fight wildfires. Unfortunately, little was known about the restorative properties of fires in some ecosystems and how some species may even rely on it for regrowth. In 1934, national forest supervisors and wilderness advocates proposed to not use fire suppression in backcountry areas where it would not be impactful to humans (Pyne 1982). This was overturned and full fire suppression continued to be the management policy of the USFS until the 1970's.

In the middle of the 20th century, there was a shift in policy change. Dr. Starker Leopold, the Secretary of the Interior at the time, helped put out a report in regards to how wildlife interacts with several ecosystems within an area and how fire can impact this. The report, released in 1962, also suggested that areas should be managed by ecosystems and less by how borders are made by state or national park lines (Leopold et al. 1963). This idea encouraged ecological management teams to recognize fire as an ecological process and to start experimenting on how wildfires could be mitigated instead of by complete suppression. Wildfire simulation methods with break lines were attempted as opposed to complete fire containment. With the help of forest and fire ecologists from several National Parks and Monuments all over the western United States, there was a huge push to move towards methods that allow areas to burn under supervision, sometimes for months at a time.

This policy was well accepted until the 1990's, when three major wildfire events showed that prescribed burns can also become out of control if not done properly (van Wagtendonk 2007). This caused criticism of fire mitigation techniques and caused officials to stop all prescribed burns from happening in all areas. Plans were rewritten in accordance to this change, but natural wildfires continued to get bigger and out of control despite no prescribed burns. Agencies throughout the United States were unable to decide on a final conclusion in how to move forward, so by the year 2000, agencies that manage wildlands had differing implementation tactics in how to deal with wildfires. Departments that have historically fought wildland fires include the Bureau of Indian Affairs (BIA), Bureau of Land Management (BLM), USFS, USFWS, National Park Service (NPS), and state ran fire protection agencies such as the California Department of Forestry and Fire Protection (CAL FIRE).

III. Current Wildfire Occurrences in California

Wildfires have been rapidly increasing in size and number throughout the United States. This has been a common theme found in research done in the last 30 years (Westerling 2016). Situated within this fire inclined territory is California. In this state alone between the years of 2010 and 2017, records show that wildfires have doubled in size and average annual area burned since the 1980's, approximately 20 years after policy had changed to stop the complete suppression of wildfires (State Board of Forestry and Fire Protection 2018, Figure 1). Size and area are not the only increasing metrics related to wildfires occurring in California. There have also been an increase in severity and intensity of how quickly wildfires burn (Jain et al. 2004).

Wildfire intensity is the rate at which the fire consumes fuel, while wildfire severity is the impact at which the fire has on vegetation, soils, buildings, watersheds, and so forth.

Some of the largest and most destructive California wildfires in recent history have occurred in the last couple years (CAL FIRE 2019). The River Fire and Ranch Fire collided in July of 2018 creating the Mendocino Complex, a wildfire impacting Colusa, Lake, Mendocino and Glenn counties. It took approximately two months to completely extinguish and burned 459,123 acres, the most area burned on record by a wildfire in the last 85 years. In November 2018, the Camp Fire started in Paradise, California in Butte County. This fire ripped through the entire town of Paradise, causing approximately 18,804 structures to burn and 85 deaths. It essentially destroyed the entire town, displacing many of the people that were able to survive the fire and escape in time. More locally, the Tubbs Fire started in October 2017 and burned large portions of Napa, Sonoma, and Lake counties. It burned approximately 5,643 structures and there were 22 fatalities. Because of the large population of people living in these and surrounding counties, it also caused a lot of issues with unhealthy air quality. The cause of wildfires range from fallen powerlines, lightning strikes, or human related causes (CAL FIRE 2019)

Current policy related to wildlands and how fire containment occurs in the state of California is decided upon two main departments: state funded CAL FIRE and federally funded USFS. Fire fighters that work for CAL FIRE cover over 31 million acres of wildlands across the state. Specific counties with high concentrations of human populations and large areas of wildlands also contract out CAL FIRE to act as their main providers of wildland fire management. Fire management provided by CAL FIRE is regulated by the State Board of Forestry and Fire Protection. The 2018 Strategic Fire Plan for California states that the most updated goals revolve around fire protection, natural resource management, and fire suppression efforts (State Board of Forestry and Fire Protection 2018). The goals focus on teaching fire resilience of wildland environments, promote local planning, and integrating implementation of fire and vegetative fuels management practices that align with similar priorities of the landowner or manager (State Board of Forestry and Fire Protection 2018). CAL FIRE works with land managers to perform wildfire mitigation techniques when necessary.

Jointly, the USFS manages areas that are located in national forests. They also work closely with state, tribal, and municipal areas to help determine what would work best in each scenario. The USFS recognizes that fire suppression has become a major influencer for longer wildfire seasons and has recently developed a new framework to determine where areas should focus on fire mitigation strategies, such as prescribed burns, and other areas that should focus on complete fire suppression when needed (US Department of Agriculture 2018). Areas with a higher UWI and human population would most likely use complete fire suppression for safety reasons. They also focus on introducing new technologies and management tools that may have not been utilized by state programs in the past. Finally, they similarly feel that doing the right work locally for what is best for the surrounding community is important.

Current fire intervals can be found by using the LANDFIRE website (Rollins et al. 2009). All estimates are wavering, most ranging from either 0 to 35 years or 35 to 200 years. There are currently a total of 5 fire intervals. Although intervals are extremely variable, the value of this data appears when using it in addition with an updated fire interval map. This map can be found on the LANDFIRE website. The locations of specific fire regimes is defined by vegetation dynamics, fire spread, fire effects and spatial context (Rollins et al. 2009). All 5 fire intervals can be found in the state of California, with the 0 to 35 year intervals running along the coast, north part of the state and eastern part of the state. The southern part of the state contains mostly areas that have fire intervals of 35 to 200 years. This is currently useful for wildland managers and fire ecologists in order to predict how wildfires will move and how wildfires may interfere with known vegetation in fire imperiled ecosystems.

IV. Future Wildfire Projections in California

Climate change is expected to shape future wildfire patterns in a significant way. Ozone depleting substances, such as greenhouse gases, have increased in the last three centuries, causing CO_2 to be trapped in the atmosphere and the global temperature to have increased. As indicated by recent studies reported in 2006, the average global temperature increases by roughly 0.2° every 30 years (Hansen et al. 2006). This temperature change is expected to increase over the span of less time in the future and will assume a critical role in fire regimes in all ecosystems and wildfires. Higher temperatures will prompt longer summers, less snow melt and drier ecosystems overall, which will likewise expand the window for when wildfires can happen in a single season (Westerling et al. 2006). Lightning strikes currently play a major role in how wildfires start in rural areas during hot, summer months. Romps et al.(2014) made a model to determine the rise of lightning strikes in the future. Their study demonstrated that there is expected to be an increase of lightning strikes by about 12% for every degree Celsius rise in global average air temperature.

Humans have a noteworthy impact in where wildfires take place, how they spread and how often they occur. In the article titled 'Human Influence on California Fire Regimes' by Alexandra Syphard (2007), researchers demonstrate how human lives and structures can change spatial patterns of fire regimes for any given ecosystem. Population trends in California have continued to almost triple since the 1960’s, and with increased populations comes more urban development and unpredictable fire activity. This means that there is a larger WUI and more potential for fire risk, possibly adding to an increase in wildfire size and number.

The mismanagement in ecosystems throughout California’s history has assumed a major role in creating unhealthy and undesirable habitats for many species types. The constant putting out of wildfires in less urban areas has caused shrubs, grasses and tree stands to be older and more over crowded than what they been in the past, with less biodiversity. With over crowded flora comes less water and nourishment for each individual and more fire risk. For those individuals that cannot make the intolerable drought and hot weather, bark beetles can also play a role in decomposing the tree for regrowth. In a healthy habitat, this is normal. But in a habitat that is overran by already unhealthy and competing vegetation, more dry and decomposing plant matter can lead to more severe and intense wildfires (Commission on California State Government Organization and Economy 2018).

Lastly, wildfires have been recorded in a wide range of ecosystems where vegetation is present and acts as a fuel source. Forested areas are a clear example of an ecosystem that is impacted by wildfires, causing devastation to large portions of northern California (Westerling et al. 2006). Grasslands can likewise be a problem however, highlighted by N. Philip Cheney (et al. 1998) in Australia and horrifically documented in the more recent wildfires occurring in the more urbanized areas of Santa Rosa, California during the Tubbs fire in 2017. Riparian regions and riverine environments additionally regularly burn (Bendix et al. 2017), causing water ways to be contaminated and obstructed throughout California. Rapidly spreading wildfires in Southern California's chaparral and coastal scrub ecosystems can aggressively burn, causing significant erosion problems and abrupt changes in the area (Zedler et al. 1983). Deserts situated in the southeastern part of California can also burn, as highlighted in "Spatial and Temporal Patterns of Wildfires in the Mojave Desert, 1980-2004" by Matthew Brooks (et al. 2006). Here, he documents wildfires occurring in lower and middle elevation deserts, possibly due to non-native species plants that have accumulated in the area over many decades. This information shows that all ecosystems are at risk for a possibility of increased wildfire encroachment if predictions about warmer global temperatures and increased drought are true.

V. Wildfire Mitigation

There are many ways to implement wildfire mitigation strategies that do not include complete fire suppression. As mentioned previously, fires are sometimes beneficial to species and ecosystem health and growth. For example, fire helps with seed germination and self-pruning for a higher population in pine trees (Rodríguez-Trejo et al. 2003). Fire has also been known to help eliminate invasive species for native species that are more resilient to burning by wildfires (Brooks et al. 2006). In the case of all species that fall under the USESA, populations are extremely small and diminishing. The idea behind the USESA is to do everything possible and within reach to save these vulnerable and unique species. Along these lines, even though different ecosystems may have different fire regimes, it is most essential to take into consideration the biological, physiological and life traits of these ES and TS. Specialists have argued that conservation should happen at the ecosystem level (Lindenmayer 2007). In most cases, this is the best strategy, as it not only helps the one species of interest, but it can also help restore the ecosystem for surrounding species and relied upon ecosystem services. However, ES and TS are special cases where species conservation and preservation should be top priority. Therefore, it is crucial for the appropriate wildfire mitigation strategy to be used near ES and TS critical habitat.

Besides complete fire suppression, there are numerous methods for wildfire mitigation techniques that occur across the country and throughout the world. Prescribed burns are a noteworthy method, which consists of purposefully setting fires in a controlled manner, so that wildfires do not burn at high intensity or severity. Prescribed burns are a method that utilize a controlled fire situation that is started by a fire technician. It is monitored and put out over time to mimic a low intensity burn. The primary goal of a prescribed burn is to prevent surface or tree replacing fires that could otherwise be threatening to nearby structures and natural resources (Arkle et al. 2010). Another popular method is thinning clippings of shrubs, bushes, and trees (Brunson et al. 2004). This creates space for incoming growth of nearby plants and allows for natural wildfires to have less accessibility to jump from plant to plant. Brush removal is also another method where any extra plant surface matter that has built up in the ecosystem floor is collected and transferred to another site (Brunson et al. 2004). This stops natural wildfires from spreading across the ecosystem floor more quickly than they would have otherwise. Fire breaks are also often utilized in areas where there is space to deplete plant matter on the ground as to create a line in the vegetation and stop fire from spreading. Finally, livestock grazing is also sometimes used in areas where there are large amounts of vegetation on the ecosystem floor. Livestock will eat grasses and extra plant matter that may have built up on the ecosystem floor so that natural wildfires will spread less quickly.

VI. Federal Lands and the Endangered Species Act

Strategies for federal wildland conservation, preservation, and protection throughout North America are unique to other places on earth. The model used, referred to the North American Model of Wildlife Conservation (Organ et al. 2012), paints an extremely clear picture. Wildlands are intended to be made for all public use, giving universal ownership to every citizen. These areas should be designated and managed respectfully and responsibly in a way that keeps wildlife conservation efforts as the primary objective. These values are likewise upheld in the state of California, found on the west coast of the United States. California contains 85 million acres of land classified as wildlands, which make up commercially, privately and government-owned areas (CAL FIRE 2012). These wildlands provide wildlife critical habitat for many species populations that are dwindling in size.

Permitting the protection of these dwindling populations, the federal government began an environmental law in 1973, called the Endangered Species Act. The USESA was enacted into legislation by President Richard Nixon and was designed to implement provisions found in The Convention on International Trade in Endangered Species of Wild Fauna and Flora or CITES (USFWS 2015). Scientists, lawyers, and politicians came together to write the final legislature measure, which states that this law is required to provide conservation and ecosystem preservation for species that are considered either endangered or threatened (Williams 1973). In order for the law to work properly and efficiently, there are two main requirements that are necessary. The first is a spatial area that can be protected in order for the species to thrive, also known as critical habitat. The other essential requirement is a recovery plan, which creates goals, tasks, future threats and the estimated cost to carefully manage and increase population sizes. Both requirements will be explained in detail in later reading material.

According to ECOS, there are approximately 1634 ES or TS that live in the United States. When being organized by species group specified by TESS, there are a total of 14 unique species types in California: Amphibian, Arachnid, Bird, Clam, Conifer and Cycad, Crustacean, Fern, Fish, Flowering Plant, Insect, Lichen, Mammal, Reptile, and Snail. Each species found within these categories are extraordinary in their own way and hold an important value that is irreplaceable. When one of these unique species winds up jeopardized, it is an indication that the biological community and surrounding ecosystem is gradually becoming less stable and resourceful. Without healthy ecosystems and ES and TS that help provide them, humans run the risk of giving up ecosystem services that are depended on regularly.

Most ecosystem services provided by ES and TS are often overlooked and forgotten about because of their continual role in our everyday lives. Ecosystem services are divided into four categories (Daily et al. 2008). Provisioning services include natural services that provide directly for human use. This includes medicinal plants and animals as a food source. Regulating services are benefits that are not necessarily seen but are taken advantage of regularly by all species on earth. Air and water purification, decomposition of wastes, and stabilizing processes are examples of regulating services. Cultural services support spaces that are accommodating to people for their enjoyment. This can be for reasons that represent esthetic beauty or spiritual stimulation. Finally, supporting services are the preservation of many of the services listed above. This can come from humans as maintenance of other services to make sure that ecosystems as functioning as they should. Ecosystem services are provided through very complicated processes, and wildlife is needed as part of the equation in finalizing these necessary ecological processes.

Many species that are found under the USESA are involved in ecosystem services in some form or another, and would cause instant catastrophe if they suddenly became extinct. For example, many species of oysters are ES or TS and are known to be a part of the regulating ecosystem service as water purifiers. Likewise, many insects that are either an ES or TS act as pollinators to provisioning crops. Some plant ES or TS even play an ecosystem service role in climate control, flood protection, and carbon sequestration (Endangered Species Coalition 2018). Extinction causes interruptions within the food chain, which can decrease populations and biodiversity in a community and throughout the food web even further (Polidoro et al. 2010, Srinivasan et al. 2007). Extinction can also decrease ecotourism and recreational activity, which can lower overall revenue and income in some industries (Yoskowitz et al. 2009). Lastly, ES and TS can provide natural medicinal cures for diseases, as well as act as pollinators in agriculture (Endangered Species Coalition 2018). ES and TS play a very important role to humans and the surrounding ecosystems that they consider critical habitat.

VII. Critical Habitat and Recovery Plans

Critical habitat is extremely important in assuring that each ES and TS gets the appropriate space needed for the conservation and protection of the specific species found under the USESA. Regional areas recorded as critical habitat are locations that are needed to sustain and fulfill the physical and biological traits of species to protect and sustain populations. Physical and biological traits include cover and shelter, essential nutritional requirements, space for the population to grow, and sites needed for breeding and rearing offspring (USFWS 2017). Because of this reason, critical habitats are unique and individualized to capture the species' needs. These regions usually consist of habitat that are currently being utilized by the species, along with areas that may be essential to their conservation in the future. Hopes are that, in these designated areas, destruction and modification to the area will be prohibited, and funding will continue to be allocated by the United States federal government to ensure the protection and studying of the species.

Critical habitat is supposed to be designated within one year after being listed as a species, as specified by section 7 of the USESA. Biologists, species specialists and spatial analysists from the USFWS and NMFS cooperate and work together to determine where critical habitat should be located. These areas are not often updated to reflect current ecosystem changes, despite how helpful these revisions could be for the conservation of these species (Hodges 2008). It is also sometimes difficult to find this data in a spatial format. Because of this, many ES and TS are often underrepresented in spatial analysis. For example, out of the 1634 ES and TS found in the United States under the USESA, only 688 of them have critical habitat spatial data. In total, there are approximately 297 ES and TS found in California today, and only about one-third of them have critical habitat spatial data. In this study, approximately 112 ES and TS are analyzed. These 112 ES and TS make up some of the 9 out of 14 ES and TS types found in California according to TESS. These species are either land or freshwater dwelling due to the nature of how this GIS project was performed.

While the USESA requires the USFWS and NMFS to designate and assign critical habitat to these species, not all of the essential habitat available makes it into this spatial reference. Pre-existing developed areas are often excluded, such as buildings, roads, airports, parking lots, etc. Privately owned lands are also often excluded as long as an on-site examination has been performed. On the off chance the ES or TS of interest is found on private land, the private landowner may be affected by USESA laws. If the ES or TS of interest is not found despite the area being prime critical habitat, the private landowner will not be impacted. If critical habitat is found in military areas, the military branch owner will be the acting member to participate in conservation and preservation efforts for the ES or TS.

Recovery plans are required in order for a species to be considered as an ES or TS within the USESA. They act as mandatory provisional goals and tasks in attempts to increase population sizes, while including any future threats that may impact the overall goal. Recovery plans introduce timelines and estimated costs that may add any additional stress to the project. They help in providing speedy, step-by-step guidance to the recovery process for an ES or TS and must include a description of site-specific management actions (Mahoney et al. 2018). They are written by wildlife biologists and species specialists. Although recovery plans are mandatory, a recent study in 2018 by Jessica Mahoney showed that a quarter of ES and TS throughout the United States were lacking recovery plans and over half of them were more than 20 years old. This means that they also most likely do not include wildfire encroachment if wildfires were less of a problem when they were written. Data recorded in this study hopes to ultimately help with recovery plan updates to include fire ecology and mitigation strategies in future plans.

VIII. Wildlife and Wildfires

While wildfires can occur in all ecosystems and habitats where vegetation is present, reports show that wildfires similarly impact all kinds of wildlife. This can be seen directly through research that has been done on different kinds of wildlife and what symbiotic relationships one species might have on another. Wildfire impacts wildlife in various ways. For example, small mammals that are less adaptable than their counterparts have been documented to cover less range in ground cover that is burned compared to more generalist species similar in size (Roberts et al. 2015). This could eventually prevent some small mammals from using once accessible critical habitat, and creating less biodiversity in a particular area. Similarly, birds are impacted by wildfires. California spotted owl nesting habitat is impacted by wildfires regularly due to the increase in wildfire severity and by decreasing the amount of tree stands available for future nesting (Stephens et al. 2016). These areas that once burned regularly did not take as long to recover from a wildfire. But since fire regimes have changed, the ecosystem where nesting is now found can take much longer to recover. Insects decrease in population directly after a wildfire because of the overall slower mobility of insects (Swengel et al. 2001). Fish species are also often impacted by wildfires (Dunham et al. 2003). Wildfires can produce contamination that enters the water table through run off. This run off creates sediment that can impact fish and amphibian health and reproduction. In most cases, not enough research has been done on wildfire mitigation techniques and how it can impact ES and TS critical habitat. It is therefore very important to continue research and determine how ES and TS interact with their ecosystems when fire is present.

Analysis Chapter

I. Macro GIS Analysis Results

A story map demonstrating information for all raster files by year from MTBS (Figure 2) and separated ES and TS total critical habitat shapefiles categorized by TESS (Figure 3) were used in this analysis. I found critical habitat spatial data for 9 out of the 14 unique ES and TS groups in California, with each of them having a different assortment of species categorized in each group (Table 3). Among the nine unique ES and TS groups, eight of them had some kind of wildfire inundation in their critical habitat. The snails group was not exposed to wildfire in their critical habitat at some point between 1984 and 2016. The amphibian, bird, crustacean, fish, flowering plants, insect, mammal, and reptile groups were exposed to wildfire between the years of 1984 to 2016.

Wildfire severity was separated between low, moderate, high and total wildfire severity between each year to determine whether there were differences between wildfire severity and if one severity impacted ES and TS critical habitat more than another. Affected regions for each ES and TS grouping was normalized by the total area of critical habitat for each group. Figure 4 summaries this data. There was a low correlation between wildfires that produced specific burn severity over time and wildfire encroachment in ES and TS critical habitat for any of the species groups. There was also a low correlation between total area impacted by total wildfire exposure and ES and TS critical habitat.

Because of the low correlation between wildfire inundation over time and ES and TS critical habitat, a table calculation was utilized in Tableau software. This table calculation, called a window sum analysis, adds data points together within a certain defined window to determine what future trends can approximately occur if the past trends hold any truth. A window value of 11 years was used to reflect historical fire regime data produced by van de Water in 2011 (van de Water et al. 2011). Eleven years was determined to reflect the lowest average time interval between historical fire regimes in all ecosystems in California. As expressed previously, fire intervals are complex and have recently undergone drastic change due to human intervention and changes in the ecosystem. In this initial analysis, species categorized under the

TESS system as ES and TS amphibians, birds, and insects were expected to have more wildfire inundation and exposure in their critical habitat when using all wildfire severity types (Figure 5).

II. Micro GIS Analysis Results

ES and TS amphibians, birds, and insects were presumed to have more wildfire inundation and exposure in their critical habitat in the future by way of using a window sum analysis. All three species categories were ungrouped to show individual ES and TS critical habitat from 2018. These individual shapefiles were overlaid utilizing GIS and compared to wildfire raster datasets from MTBS starting from 1984 to 2016 similarly to what was done in the above analysis. There were a total of six ES or TS amphibian species, nine bird species, and eight insect species located in California (Figure 6). Metadata for these ES or TS include common names, scientific names, total critical habitat area in hectares and results of wildfire impact (Table 4). All six amphibian species, eight out of nine bird species and two out of eight insect species were directly impacted by exposure to wildfire, resulting in a total of 16 species. Tableau software was used to visualize the results (Figure 7, Figure 8, Figure 9). Species with the most wildfire exposure directly impacting their critical habitat were chosen in order to move forward with. Biological, physiological, and life traits were researched for these species, while recovery plans and grey literature were compared for these five species, which is highlighted below.

III. Arroyo Southwestern Toad (*Anaxyrus californicus*)

The Arroyo southwestern toad (*Anaxyrus californicus*) is a federally endangered amphibian species that is found in patchy coastal regions between central and southern California, ranging in elevation below 1950 meters above sea level. Populations are found near riparian areas with light shade and clear, standing water. Regions needed for this species to thrive are usually naturally wooded and sandy, and can often be found in valley foothill or desert ecosystems that also contain willows, cottonwoods, and sycamore trees. The tree cover is used to keep the toads cool during hot temperatures. Approximately 6 out of the 22 historical populations contain up to 12 individuals only. These toads are mostly nocturnal, but younger Arroyo southwestern toads can tolerate higher temperatures, which means they are sometimes active during the day. They feed during the night and often walk when feeding instead of hopping. These toads feed on snails, crickets, beetles, ants, and other insects. While these toads do not migrate, they can travel up to 2.5 miles along riparian areas looking for potential mates. Pools of water are required for procreation of this species, as eggs are deposited on the bottom of quiet and clear streams or ponds. The eggs attach to gravel, leaves, or sticks. Adult sexual maturity can take up to two years. Breeding season for this species is between March to July and can last till September, while immediately hibernating after until February or March by creating a hole into the ground or stream channel.

The recovery plan for this species was finalized on July 24th, 1999, approximately 4.5 years after this species was added to the USESA (USFWS 1999). The plan is approximately 120 pages and highlights many tasks that need to be done in order to assure the species recovery. Some of these tasks include finding ways that humans can minimize habitat impact in camping areas, construct paths under roads to increase safety from vehicles, and identifying breeding sites in order to focus on restoration efforts. This species lives in a very dynamic region and has evolved to be able to withstand wildfires in the past because of it. Due to human interference, this may not be the case anymore. Studies in the past have shown that fire regimes have changed in more upland areas due to invasive plant species. This leads to downstream erosion in Arroyo southwestern toad habitat, causing reduced breeding areas. In the recovery plan, wildfires are named as large events that can impact population metrics, synonymous to human recreational disturbances, floods and introduced invasive predators.

One of the tasks in the recovery plan, task 4.9, is specifically there to direct the assessment regarding wildfires effect Arroyo southwestern toads. This includes research in regard to wildfires impact the vegetation patterns of the toad, reproduction and recruitment, and habitat suitability. Information stated in the recovery plans show that this was supposed to be done between 1999 to 2003. Unfortunately, there is not an area on the USESA website to determine the progress of this research. However, there is an area that states that a graduate student worked on a project to determine how the recovery plan should be updated to reflect data gathered concerning wildfire related impacts to critical habitat. This research was supposedly done between 1995 and 1999, but again, there is not a link or anywhere to find progression of the updated recovery plan reflecting this information. There was not any further information or biological opinions on the federal ECOS site related to wildfires and critical habitat for the Arroyo southwestern toad.

IV. California Red-Legged Frog (*Rana draytonii*)

The California red-legged frog (*Rana draytonii*) is a federally threatened amphibian species that is found in isolated areas starting as far as north as the Mendocino coastal ranges down to the most southern coast of California. This frog is also found in areas wrapping around the eastern most parts of the San Joaquin Valley in the Sierra Nevada mountain range. These frogs can be found below 1200 meters above sea level. California red-legged frogs can be found near ponds and riparian areas that are located near upland regions that contain densely wooded vegetation and open areas. They need permanent pools throughout the year in streams, marshes, or ponds. They use plants on the shoreline of the ponds they live in for shade and larval development. Current populations have declined 90% in all critical habitat. In coastal areas, these frogs are active all year round, whereas in non-coastal areas, they are known to hibernate throughout late summer and early winter by burrowing into gravel or sand. They have a highly diverse diet of insects, crustaceans, worms and snails. These frogs are highly active in their aquatic environment. They have been known to travel up to 2 miles during rainy nights looking for food. Predation of this species mostly occurs from other aquatic vertebrates and invertebrates throughout the frog's life cycle. Breeding occurs from January to July for frogs that are located in southern California, while in northern California, it occurs from March to July. Females can lay as many as 4000 eggs in one harvest, but they need the proper vegetation in the area to attach the eggs below the water surface so that they do not wash away. Adults take up to three years to become sexually mature.

The recovery plan for this species was finalized on May 28th, 2002, 6 years after this species was added to the USESA (USFWS 2002). This plan is 180 pages and includes recovery guidelines that focus on the major issues that are decreasing the population of the California red-legged frog. This includes removing dams to develop proper water flow regimes to restore habitat, control invasive plants that could be impacting the species, and eliminate contaminants from entering the ecosystem. The recovery plan also suggests that the authors are fully aware that wildfires are a problem for this species. But unfortunately, there was not a direct reason given as to why wildfires could have such an impact.

Recovery action number 9 states that guidelines for fire management practices should be developed to decrease incidental impacts to the California red-legged frog. In this guideline, there are strict recommendations on how to undergo wildfire mitigation and management without contaminating the habitat. Techniques include prescribed burns in the upland habitats only in times when the species is known to be done breeding for the year. Prior to doing this, regions that are often used for breeding will be fenced off and specialists need to inspect and monitor the area to make sure frogs are not located in the prescribed burn areas. When performing the prescribed burns, fire retardants are restricted to be dropped anywhere near wetland habitat areas. This recovery plan recommends that state and federal parks evaluate compatibility with these methods in the current fire management plan in these specific ecosystems and watersheds where these frogs are found. Unfortunately, there is no information on how wildfires directly impact this species or the effects of wildfire exposure to this species critical habitat. Biological opinion articles also do not have any mention of wildfires in relation to critical habitat for the California red-legged frog.

V. California Condor (*Gymnogyps californianus*)

The California condor (*Gymnogyps californianus*) is a federally endangered bird species that is found in the semi-arid, rugged mountain ranges cupping the southern most regions of the San Joaquin Valley. These birds can be found up to 3000 meters in elevation. They require isolated cliffs, caves, and large trees to roost in, along with large areas of remote country for scavenging, such as savannah foothills, grasslands or foothill chaparral. They get most of their water from their diet. It is unclear as to historically what the population size was for the California condor, but in the mid 1980’s, it dropped to approximately 27 individuals in the wild. Currently, there are approximately 440 individuals in the wild. This was done in part by collecting all condors from their wild habitat, breeding them in zoos, and slowly releasing them back into the wild when they were sexually mature. This is still currently being done to increase population metrics. These birds can live up to be 45 years old and take about 6 years to become sexually mature. They forage in wide open spaces on scavenged carrion, mostly deer, cattle, or sheep. These birds are not migratory, but they have been known to travel up to 100 miles in search of food. California condors do not have any direct predators, as they are the largest bird in North America, having a wingspan of up to 10 feet. The decreases in population trends are directly related to many factors, including pesticides, habitat destruction, lead from bullets found in scavenged food, and mistaking larger windmills for areas that are safe to land on. These birds lay their eggs on to a bare surface. They breed annually and court one another in October. Eggs are laid between February and May. Fledglings rely on their parents for several months before becoming independent.

The first recovery plan for this species was finalized in December of 1974, approximately 7.5 years after this species was added to what would then lead to the USESA. Since then, there has been a total of four revisions for this plan; one in February of 1980, another one in July of 1984, and the most recent revision on April 25th, 1996 (USFWS 1996). Since 1996, there have been many reviews and regional conservation plans, but the most recent official recovery plan is from 1996. This plan is approximately 70 pages and focuses on the new population of California condors who are being released into the wild. Main strategies include how to monitor condor populations, how to release condors, how to minimize death of the condor, and how to conserve habitat for the condor. Unfortunately, there is not any information in the recovery plan about wildfires or wildfire mitigation related to the California condor despite critical habitat being drastically sensitive to wildfire encroachment. There is also no proposed recovery plan changes or biological opinion articles related to wildfires and how California condors can be less drastically impacted by them.

VI. Coastal California Gnatcatcher (*Polioptila californica californica*)

The coastal California gnatcatcher (*Polioptila californica californica*) is a federally threatened bird species that is found in fragmented coastal regions in southern California, located north of the San Diego area and running as far as south as Baja California. Highest recorded elevations that they have been found include areas below 1000 meters above sea level. Coastal California gnatcatchers require a low coastal scrub habitat that is plentiful of drought deciduous plants for roosting, nesting, and cover. In 1997, populations were estimated to be approximately 2900 pairs left in the entire United States. These birds are active all year round and do not migrate.

They forage for ground and shrub insects, and use low lying plants for cover. They get most of their water from their diet and do not need a permanent water pond of any kind. Coastal California gnatcatchers weave small, deep nests from many kinds of material, including leaves, fibers, plants and spider silk. They are monogamous and lay their eggs between April and May. Fledglings are dependent on their parents for approximately 10 days before becoming independent.

This species was added to the USESA on March 30th, 1993, but unfortunately there is not yet a recovery plan for this species. Because of this, there are not any proposed suggestions on how to change it. There are two biological opinion articles relating wildfire and critical habitat for the coastal California gnatcatcher. Both of these articles are specific to regions located in San Diego county. These articles are not related to how wildfire impacts the species or critical habitat, but more relates to wildfire mitigation practices and how they could impact populations.

In the first opinion, the city of Chula Vista proposed vegetation management in Rice Canyon to help with wildfire management (USFWS 2016a). By doing this, vegetation would be thinned and removed. The article, written by appointees from the USFWS, addresses on if the thinning will impact coastal California gnatcatcher populations. The author determines that there should not be a decline in population by doing this.

The second opinion addresses a firebreak that was being requested by a naval base that also shares critical habitat for the coastal California gnatcatcher (USFWS 2016b). The firebreak only impacts approximately 2% of the critical habitat found in this area. By doing this, herbicides would be used to eliminate grasses from growing in these areas. Although the herbicides used do not impact animal health in a lab setting, this may not be the case in a wildlife setting. The herbicides suggested would be used less overtime due to the nature of how herbicides work. Since the coastal California gnatcatcher would most likely find other areas to nest outside of the firebreak zone where there is no shrublands, they found this to be a satisfactory plan if followed up by a few specific details. The herbicide used for this purpose has to be registered with the Environmental Protection Agency. Lastly, in time, mowing will work just as well as using herbicides. The naval base responsible for directing the generation of the firebreak is required to use as little herbicide as possible and use mowing as an alternative when appropriate.

VII. Quino Checkerspot Butterfly (*Euphydryas editha quino*)

The Quino checkerspot butterfly (*Euphydryas editha quino*) is a federally endangered insect species that is found in patchy southern California regions, starting at the coast and running east to drier, desert ecosystems. This includes areas near major metropolitan cities, such as Santa Ana, down to the southern border of California, and as far east as the Anza-Borrego Desert. These butterflies are dependent on specific plants populations in their habitat, such as the dwarf plantain (*Plantago erecta*) and the white snapdragon (*Antirrhinum coulterianum*). Ecosystems that support these plant species include grasslands, coastal scrub, chaparral, woodlands, and desert scrub. Population values are extremely low for this species. In 2000, all but three out of the historical eight population sights contained less than five individuals. These species do not migrate and do not fly over objects that are approximately 8 feet tall. Predators include larger invertebrates. Individuals still in the larval stage feed on leaves produced by the host plant, while adults feed on plant nectar and are dependent on flower blooms. The adult life span usually runs from February through May. As summer arrives, butterflies still in the larval stage can go into dormancy if the host plant dries out. During this dormancy stage, larvae will slowly move to the ground and use ground leaf litter as cover from the elements. Host plants become rejuvenated by rains throughout the winter months, quickly progressing the larvae from being in the dormancy stage back to the larval stage. This back and forth movement from larval to dormancy stages can occur for up to two years. Because of this reason, they are directly dependent on rain fall in winter months. Adults only hatch once a year. Eggs are laid in clusters at the base of the host plant once a day for two weeks between March and April.

The recovery plan for this species was finalized on August 11th, 2003, approximately 6.5 years after this species was added to the USESA (USFWS 2003). This plan is a little over 190 pages and contains very specific recovery criteria in order to increase population metrics for this species. Major topics in the recovery plan include protecting the remaining habitat, assess and study the current populations, and find methods to recreate historic habitat and guide conservation efforts in relation to fire regimes and how they impact plant populations. This recovery plan does refer to how wildfire impacts this species, but it does not make any specific suggestions on what fire suppression methods should be done or ways to help increase native plant populations (USFWS 2003). The recovery plan directly notes that the changes in fire regime in the past due to human caused wildfires in the chaparral ecosystem is one of the major causes for the population decrease in this species. Wildfires in these areas are occurring too often, causing drastic landscape changes that wildly impact the plants that the Quino checkerspot butterfly relies on.

Future Management Recommendations

I. Recovery Plans and Critical Habitat

The USESA utilizes both recovery plans and critical habitats in order to fulfill restoration efforts in hopes to re-establish ES and TS populations. Recovery plans help with organizing ideas and tasks that are set to determine why, when, and how specific ES and TS populations can increase (Mahoney et al. 2018). Critical habitat regions for ES and TS populations determine where restoration efforts should occur for maximum population increases (USFWS 2017). The lack of a recovery plan or critical habitat could therefore eliminate restoration efforts and potentially cause a detrimental drop in population metrics. Furthermore, the USESA is a very useful and effective law when it is followed and utilized properly. Documentation has shown that, when priorities shift away from information found in the recovery plan or away from life traits of the species completely, restoration attempts can turn sour and not work as well (Mahoney et al. 2018). The following information addresses recovery plan tasks and goals, while comparing this data to information found during the progression of this project. Suggestions are made in hopes to make the recovery plans for each species more effective and efficient. Table 5 describes current recovery plan suggestions related to wildfire mitigation efforts for all five ES or TS studied in this project.

The recovery plan for the Arroyo southwestern toad states that wildfires in upland areas can cause soil erosion in direct habitat in riparian areas due to fire regime changes (USFWS 1999). Erosion can cause suitable reproduction habitat to no longer be accessible due to water not being clear and the appropriate nearby plants and soil types not being accommodating to the toads. The recovery plan also states that prescribed burns should be done in some upland areas to manage for abnormal build-up of fuels due to shifted fire regimes by humans. Specific tasks and notes include that research was being done or was being planned to assess the effects of fire on the toad and critical habitat and how it can impact populations. An updated recovery plan for the Arroyo southwestern toad needs to be revised to include research results related to wildfires and how they impact the toad. Any current research being done also needs to be included. Another issue to address is to specifically say when and where prescribed burns or other wildfire mitigation strategies can occur. In this way, there is no confusion as to what could be labelled as upland. Suggesting when this should be done is also important. Breeding season is clearly the worst time for this to be done, therefore sometime between October and January might be best. This should be stated in the recovery plan so that there is less ambiguity declaring how actions should be done when moving forward. Native plants should be planted in the upland areas to eliminate any erosion that could occur in breeding season. This should happen directly after any prescribed burns occur. Finally, similar to what is stated in the recovery plan for the California red-legged frog (USFWS 2002), a species specialist should be present during the process of performing prescribed burns to make sure that the area is safe to burn for the species of interest.

The recovery plan for the California red-legged frog outlines that wildfires are a problem for this species and can impact population values (USFWS 2002). However, it does not specifically say how these wildfires impact the species. One can only assume that wildfires impact this species in similar ways that wildfires impact the Arroyo southwestern toad. An item that this recovery plan does do well is create guidelines in respect to how to prepare wildfire mitigation efforts and how to put out prescribed fires. There are very specific actions that should be considered during an emergency effort or in a prescribed fire situation. For example, how far away should a prescribed burn be started from riparian areas and how the fire should be put out. This is to avoid contaminating critical habitat for these frogs. This is a great addition to a recovery plan in order to accumulate all data needed to move forward with recovery efforts.

This recovery plan update needs to include more research on the actual species. As mentioned above, it should include how wildfires specifically hurt this species so that better recommendations can be made. Another recommendation that is also suggested for the Arroyo southwestern toad, the timing in season for when prescribed burns occur is critical and should be mentioned in the recovery plan. Breeding season runs from January to July and prescribed burns should not be started during this time. Finally, similarly to the Arroyo southwestern toad (USFWS 1999), since these ecosystems contain riparian areas, would it be best to stay away from mitigation techniques that require a fire retardation use? It may be possible to get similar results by using livestock thinning. More research should be done to determine best practices in these ecosystems.

The recovery plan for the California Condor was the first to be made in the history of the USESA and has been revised many times, for a total of four revisions. This analysis was done on the most recent recovery plan, which is the fourth revision (USFWS 1996). There is no information about wildfires in this recovery plan. That is not to be said that past recovery plans do not include information about wildfires. Past revisions actually do include information about wildfires and wildfire mitigation strategies. So, what changed? Over 14% of the critical habitat for the California condor burned in recent history. Therefore, it is important to keep this information in the recovery plan for future reference.

A couple reasons come to mind as to why this information may have been excluded in the most recent recovery plan. First, the most recent plan was created in 1996. Data shows that wildfires did not drastically increase in critical habitat for this species until the early 2000's. Therefore, wildfires were not as drastic of a situation when the recovery plan was written. Second, the California condor has had a long history of being detrimentally impacted by humans. This includes exposure to an insecticide that decreases reproductive rates, poisoning from hunters that use lead bullets and do not take their kills, and being struck by wind turbines. Currently, wildfires may pose less of an impact than other issues that the California condor is sensitive to. But as populations increase, wildfires could pose another detrimental problem for California condors, especially if the current recovery plan does not reflect wildfire mitigation efforts.

Wildfire mitigation technique suggestions to add to the recovery plan of the California condor include utilizing current technology surrounding the species. Individuals released into the wild are discharged with a GPS tracker around their neck. This is done so that researchers can visit their nests to determine their health and reproductive rates. Nesting areas can be tracked and mapped so that small prescribed burns can be performed around the nests during times when it is not the breeding period. In this way, the vegetation surrounding the nests can be slowly burned so that space can still be utilized by the condor.

The coastal California gnatcatcher does not have a recovery plan. Unfortunately, there is no information as to why there is not a recovery plan. This could be related to the lack of time and funding people in this industry often have (Taylor 2005). Regardless, there has been funding and recovery efforts done to help restore areas for the coastal California gnatcatcher. Recovery efforts also seem to include wildfire mitigation in some areas. This shows that recovery efforts can move forward without a recovery plan, but one may wonder if this is due to the fact that critical habitat for this species is much smaller than other species. Recovery efforts take a considerable amount of organization to move forward with. If there is less critical habitat to recover, efforts are most likely easier to proceed and finish with.

A biological opinion mentioning the coastal California gnatcatcher suggests that small amounts of thinning would not impact the population of this species (USFWS 2016a). A recommendation that could be added to the new recovery plan is to determine if this is true for the entire critical habitat. Eliminating all shrublands would not create a healthy ecosystem for this species because of species cover and the use of twigs and vegetation for creating nests. However, livestock thinning could be useful in eliminating some wildfire fuel, leaving just enough vegetation suitable for the species of interest. This would need to be done in times other than spring in order to not get in the way of breeding season.

The Quino checkerspot butterfly has an excellent recovery plan already put into place. There are full explanations as to how wildfire impacts the species, but more informative suggestions should be made for wildfire management strategies in the area (USFWS 2003). Wildfire management practices have always been a controversial issue in the chaparral ecosystem of Southern California. Maintaining a natural fire regime can be difficult in an area with such a large, growing human population. Most current wildfires in these areas are ignited by humans and carried by the Santa Ana winds. When this occurs too often, it can account for landscape changes from chaparral to nonnative grasslands. Therefore, large amounts of wildfire management practices have been studied in these areas. For the case of the Quino checkerspot butterfly and the plant species associated with them, wildfire management strategies currently being performed in the chaparral ecosystem should help make a positive impact for the small population. This includes complete fire suppression, mechanical fuel treatment (such as fire breaks) and clipping or cutting the vegetation (van Wagtendonk et al. 2018). If wildfires are occurring at a rate that is more similar to their natural fire intervals, it should keep plant species needed to sustain butterfly population growth. Using common fire suppression and vegetation clipping or cutting as a method for decreasing the amount of vegetation for fuel burning will help decrease the amount of likelihood that there could be an unnatural fire. However, since accidental wildfires are incredibly common in this area due to the large human population, it may be worth finding alternative measures to help increase these plant species, therefore helping to boost butterfly population metrics.

There are future predictions of increased wildfires in California due to climate change, warmer temperatures, and lightning strikes (Hansen et al. 2006, Westerling et al. 2006, Romps et al. 2014). This will cause fire regimes to change and wildfire patterns to shift. Because of this reason, recovery plans for these species need to be updated to reflect this possible encroachment in critical habitat. Realistically, it would be most helpful if all species that were impacted by wildfire incorporated some type of wildfire mitigation strategy and research related to the species in each recovery plan. Even a small mention of wildfire mitigation is a start and would be helpful in the future when new updates are written. Otherwise, this information could be forgotten about and not ever incorporated.

One surprising discovery from this project is the lack of studies that have previously occurred on how fire impacts specific ES and TS. The Quino checkerspot butterfly had detailed information on exactly how wildfire encroachment impacts the population metrics (USFWS 2003). Otherwise, there was very little data on the remaining four species as far as how fire can impact the actual species. This is important in knowing what wildfire mitigation practices should be done. Adding information about fire regimes and how invasive species impact these fire regimes would also be helpful to include in recovery plans. Often times the ecosystem needs to be restored in order for the population metrics to increase. Furthermore, some wildfire mitigation strategies may work more efficiently than others in the situation of ES and TS. For example, fire breaks are hard to utilize in this situation since most species utilize several ecosystems. By making a fire break, a fragmented ecosystem is accidentally being made. This could possibly decrease population metrics. Knowing when to do mitigation strategies according to life traits is important and should be further mentioned in recovery plans.

II. Ecosystem vs Single Species

Ecosystems are often complex and play significantly different roles to different individuals. Species benefit from ecosystem services identified as either provisionary, supportive, regulating, or cultural (Daily et al. 2008, Endangered Species Coalition 2018). Researchers often suggest that ecosystem-based restoration is more profitable and efficient than single-species restoration. For example, restoring an entire riparian area for all species use is seen to be more cost effective than restoring one single area for one single species. Lindenmayer et al. (2007) debates whether a single-species or a more ecosystem-based approach to conservation and research better prioritizes funding, time and expertise for conservation managers. Ecosystem-oriented research is more widely used presently in conservation research and restoration efforts due to its umbrella effect in helping several species. Unfortunately, the USESA must be seen as an exception. Goals defined by the USESA explicitly site that saving specific species or subspecies from being threatened with extinction is top priority. In a perfect world, both restoration strategies would be used. However, financial aid is often cut short, and one will have to take priority. Species specific research should always be done in the case for species under the USESA, but that doesn't mean that ecosystem restoration and research should be completely eliminated if funds are available.

This project demonstrates that wildfire encroachment can impact critical habitat for ES and TS at different rates in all types of ecosystems. One trend appeared upon researching where the critical habitat was for all five severely impacted species and how they each utilize their surrounding ecosystems. More of these species use several ecosystems, as opposed to just one.

This suggests that, if ecosystem-oriented research is capable, restoration efforts should be employed in areas that border several ecosystems as opposed to performing restoration in the center of an ecosystem. Multiple ecosystem-based restoration projects that are smaller and all border each other may be beneficial when funds are available. It is also important to remember this when researching wildfire mitigation methods in these sensitive ecosystems. Wildfires impact ecosystems differently, and therefore should attempt to alleviate wildfire sensitivities in all utilized ecosystems.

III. GIS

Results derived from this GIS analysis aide in recognizing GIS as a newer and emerging technology that can be used to examine large spatial datasets and direct quicker management decisions. For example, GIS was used to analyze wildfire encroachment sensitivity in smaller riparian areas to determine management strategies (Bendix et al. 2017). However, in this project, a large dataset was overlaid upon another dataset to determine what areas within an entire state are more impacted by wildfire encroachment than others. GIS has not yet been utilized in this manner for an entire state using ES and TS critical habitat and wildfire area. Upon analysis, these results give a positive outlook as far as how spatial data can be used to get specific answers about unique critical habitat. By simplifying fire regime data, this data could be utilized by environmental managers and policy makers to help update recovery plans with wildfire mitigation methods that can positively impact ES and TS critical habitat. GIS is a novel research tool that can be used in the future for other states and can direct future wildfire mitigation projects.

There are constraints to using GIS for this type of analysis though. Unfortunately, during the macro analysis of this project, a statistical correlation between the actual increase in wildfires and ES or TS critical habitat was not found. P-values were not low enough to be statistically relevant and R^2 values were somewhat low, showing little pattern over time. One suggestion for this lack of pattern could be related to human impact to fire regimes and the complete suppression of wildfires to save human lives and structures. Another suggestion could be related to the large WUI found in California, causing an increased probability as to when fires start. Both theories could be researched more in order to indicate a harder time in finding statistical relevance in the data provided.

Other limitations to this project include the progressive manner in how ecosystems are always in flux. Reasons for ecosystem change include habitat destruction, planned restoration progression, natural disasters or the introduction of invasive species. It is difficult to reflect these constant adjustments in ecosystem boundaries. Since specific ecosystems are needed in order for these sensitive species to survive, it is important to capture the most accurate depiction of each critical habitat. This spatial data is not often updated or accessible overtime (Hodges et al. 2008). Because this analysis utilizes critical habitat that is needed by ES and TS that may not be completely updated, some results from this investigation may not be accurately portrayed in the datasets presented.

IV. Final Thoughts and Future Direction

Datasets and scientific literature researched in this project help to conclude the need for many changes needed in the USESA system. The recovery plan for the coastal California gnatcatcher needs to be created, while the recovery plan for the California condor needs to be updated to include wildfire mitigation efforts (USFWS 1996). The recovery plans for both the Arroyo southwestern toad (USFWS 2002) and California red-legged frog (USFWS 1999) both need to be updated to include specific measures for wildfire mitigation technique and how it could impact direct critical habitat and directions specifying how wildfire mitigation should be done. Finally, the Quino checkerspot butterfly has a very well written recovery plan that is very informative as far as issues related to wildfire and how it impacts the species (USFWS 2003). All recovery plans need to be updated to include new research that has been done in the last 15+ years. Critical habitat spatial datasets need to be updated as well.

As wildfires increase in California and seasons become longer, critical habitat is likely going to become more sensitive to wildfire encroachment for these species. It is therefore important to update recovery plans with well-written and instructive wildfire mitigation methods needed for restoration efforts for ES and TS management. This project demonstrates that wildfire ecologists that study ES and TS critical habitat should keep a special eye on critical habitat for amphibian, bird and insect species, in particular, species studied in this project.

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Tables

Table 1. Necessary datasets needed for this spatial analysis.

Datasets	Sources
Critical Habitat for Federal ES and TS divided by species for the entire United States	CRITHAB_POLY by www.data.gov or the USFWS site using ECOS
Wildfire Severity Data from years 1984 to 2016 for the state of California	MTBS_CA_1984 to MTBS_CA_2016 (33 total files) using the Monitoring Trends Burn Severity data at www.mtbs.gov
State boundaries for the entire United States	Cb_2017_us_state_500k by the United States Census Bureau website

Table 2. United States Geographic Survey Codes for the Threatened and Endangered Species System.

SPECIES CODE First Letter	Species Groups
A	Mammals
B	Birds
C	Reptiles
D	Amphibians
E	Fishes
F	Clams
G	Snails
H	Millipedes
I	Insects
J	Arachnids
K	Crustaceans
L	Annelid Worms
M	Flatworms and Roundworms
N	Hydroids
O	Sponges
P	Corals
Q	Flowering Plants
R	Conifers and Cycads
S	Ferns and Allies
U	Lichens
V	Algae
W	Cyanobacteria and Bacteria

Table 3. A summary of how many species are within each wildlife group using TESS, which ones are impacted by wildfires, and the total area of critical habitat.

Wildlife Group Name	Number of Species within Wildlife Group	Wildfire Impact
Amphibian	6	Yes
Bird	9	Yes
Crustacean	6	Yes
Fish	9	Yes
Flowering Plant	62	Yes
Insect	8	Yes
Mammal	8	Yes
Reptile	3	Yes
Snail	1	No

Table 4. A summary of the most impacted wildlife groups, examining specific species and the total area of critical habitat belonging to each species.

Common Name	Scientific Name	Wildlife Group Name	Total Area of Critical Habitat (in Hectares)	Wildfire Impact
Arroyo Southwestern Toad	*Anaxyrus californicus*	Amphibian	40081.6387	Yes
California Red-Legged Frog	*Rana draytonii*	Amphibian	663899.781	Yes
California Tiger Salamander	*Ambystoma californiense*	Amphibian	104275.834	Yes
Mountain Yellow-Legged Frog	*Rana muscosa*	Amphibian	93011.1584	Yes
Sierra Nevada Yellow-Legged Frog	*Rana sierrae*	Amphibian	441266.071	Yes
Yosemite Toad	*Anaxyrus canorus*	Amphibia	303889.294	Yes
California Condor	*Gymnogyps californianus*	Bird	245523.538	Yes
Coastal California Gnatcatcher	*Polioptila californica californica*	Bird	80310.8859	Yes
Inyo California Towhee	*Pipilo crissalis eremophilus*	Bird	881.191728	No
Least Bell's Vireo	*Vireo bellii pusillus*	Bird	15037.5126	Yes
Marbled Murrelet	*Brachyramphus marmoratus*	Bird	244071.379	Yes
Northern Spotted Owl	*Strix occidentalis caurina*	Bird	849973.476	Yes
Southwestern Willow Flycatcher	*Empidonax traillii extimus*	Bird	15931.1769	Yes
Western Snowy Plover	*Charadrius nivosus nivosus*	Bird	6073.40986	Yes
Yellow-Billed Cuckoo	*Coccyzus americanus*	Bird	33115.9583	Yes
Bay Checkerspot Butterfly	*Euphydryas editha bayensis*	Insect	7402.49839	No
Casey's June Beetle	*Dinacoma caseyi*	Insect	242.507891	No
Delta Green Ground Beetle	*Elaphrus viridis*	Insect	392.178088	No
Laguna Mountains Skipper	*Pyrgus ruralis lagunae*	Insect	2553.04348	Yes
Palos Verdes Blue Butterfly	*Glaucopsyche lygdamus palosverdesensis*	Insect	36.803009	No
Quino Checkerspot Butterfly	*Euphydryas editha quino*	Insect	25350.4698	Yes
Valley Elderberry Longhorn Beetle	*Desmocerus californicus dimorphus*	Insect	208.25571	No
Zayante Band-Winged Grasshopper	*Trimerotropis infantilis*	Insect	4505.54145	No

Table 5. Recovery plan wildfire topics with respect to wildfire impact and wildfire mitigation methods outlined.

Common Name	USESA Date	Recovery Plan Date	Ecosystem	Wildfire Impact	Wildfire Mitigation Methods
Arroyo Southwestern Toad	12/16/94	07/24/99	Woody Riparian surrounded by Valley Foothills or Desert Ecosystems	Invasive plant species in upland areas causes changes in fire regimes and more fire than usual, causing downstream erosion in critical habitat. Fire impacts water flow for pools and sand bars needed for reproduction and life.	Prescribed burns may be appropriate as a management tool under some circumstances, such as where past fire suppression efforts have allowed an abnormal build-up of fuels.
California Red-Legged Frog	05/23/96	05/28/02	Woody Riparian Ecosystems	Wildfires do impact this species but there are not defined reasons as to how or why.	Prescribed burns should be performed in upland areas during specific seasons. This should be done at least 150 meters away from habitat. Fire retardant cannot be used to put out the fire.
California Condor	03/11/67	04/25/96 (4th Revision)	Savannah Foothills, Open Grasslands, Foothill Chaparral, and Rocky Outcrop Ecosystems	No mention of wildfires or how species are impacted by wildfires	No mention of wildfire mitigation.
Coastal California Gnatcatcher	03/30/93	N/A	Coastal Scrub Ecosystems	N/A	N/A
Quino Checkerspot Butterfly	01/16/97	08/11/03	Grasslands, Coastal Scrub, Chaparral, Woodlands and Desert Scrub Ecosystems	Disrupted fire regimes has caused invasive species to invade areas that native plants utilize that have a symbiotic relationship with the species. Fires used to play a huge role, but it is now unclear how fire impacts the species.	Prescribed burns should be implemented in small patches near critical habitat. Research should be done to determine what specific wildfire mitigation can be done to increase populations.

Figures

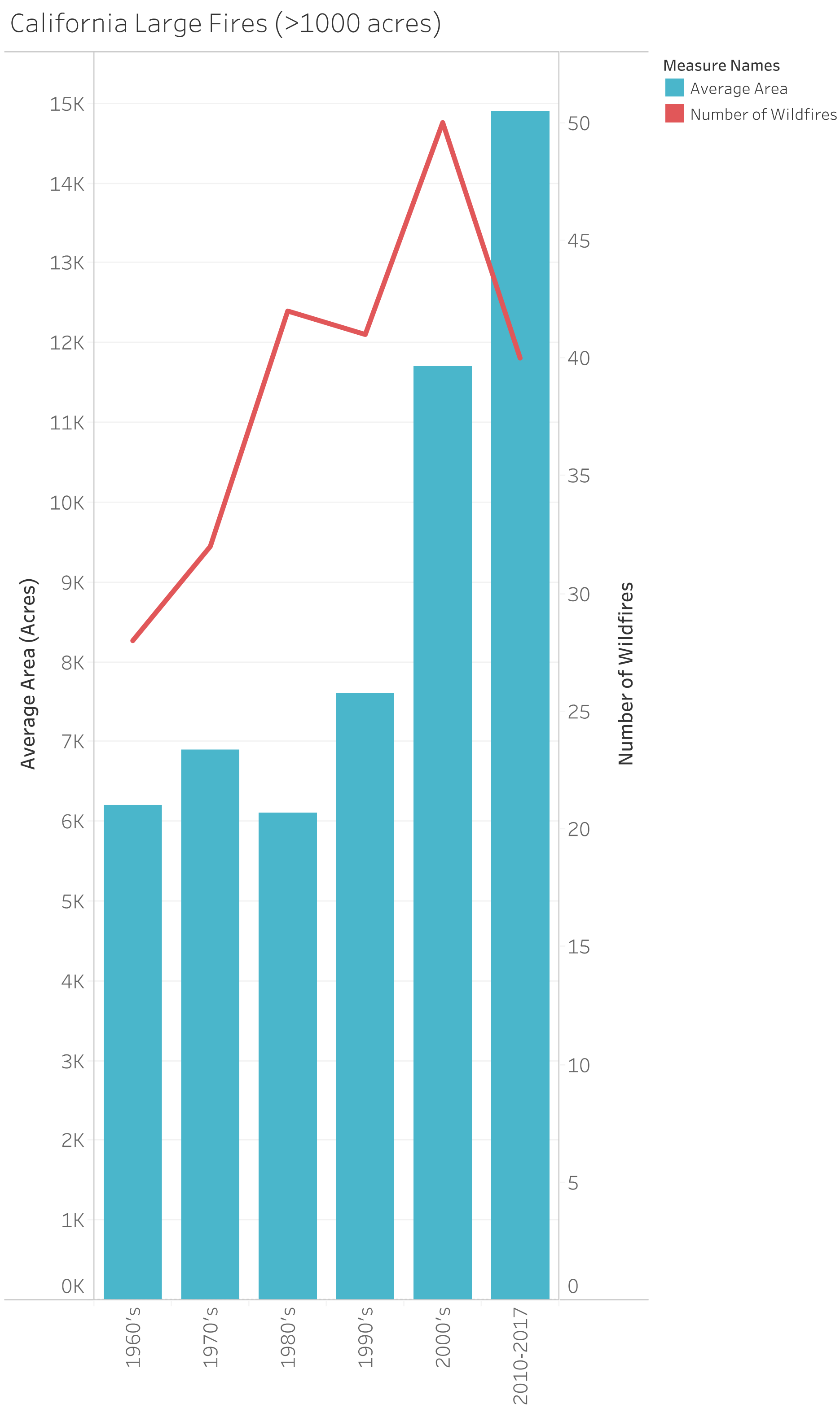

Figure 1. CAL FIRE data showing an overall increase in wildfires throughout California by area and number of burns for each decade. The last column does not symbolize a full decade (State Board of Forestry and Fire Protection 2018).

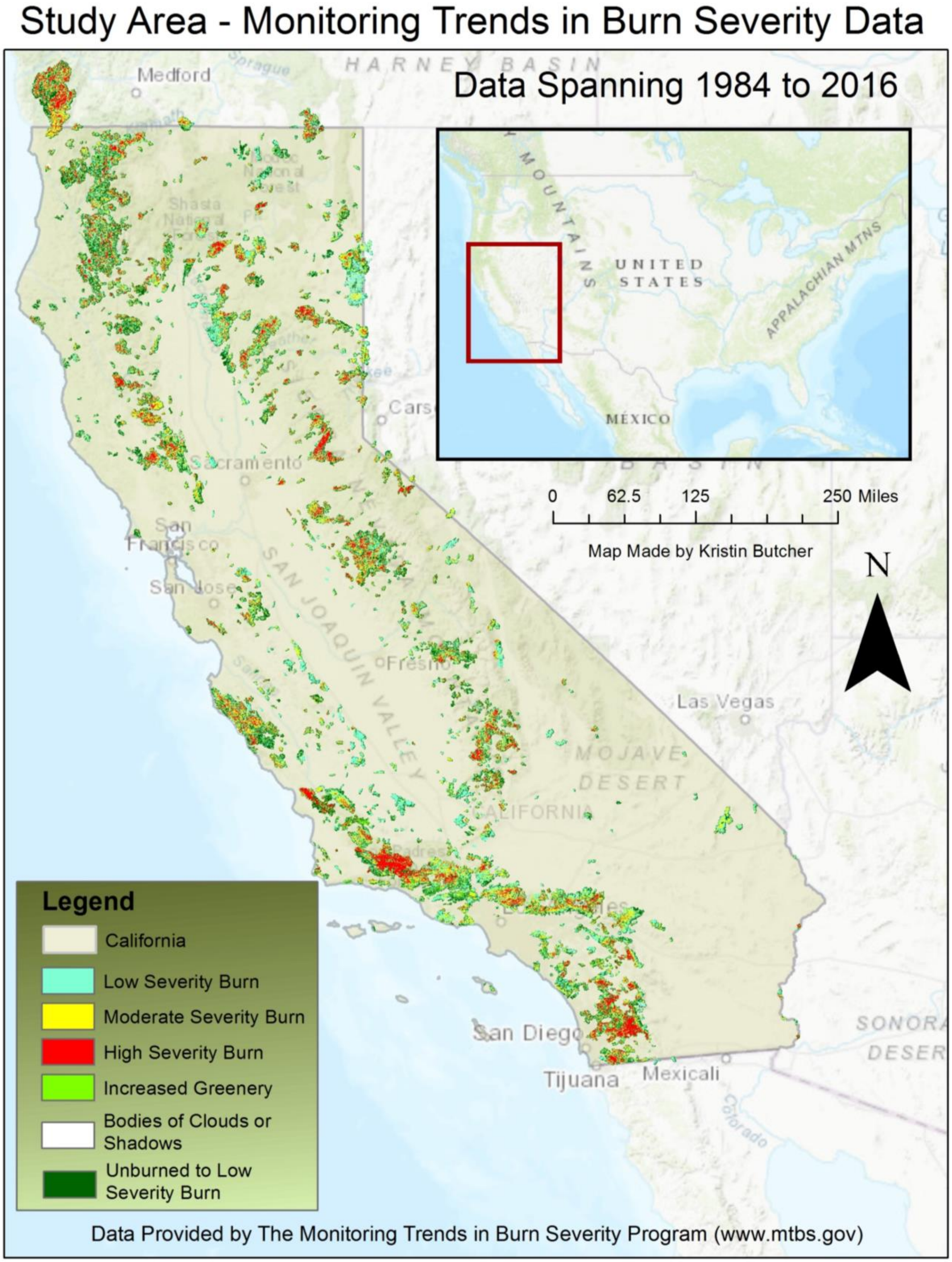

Figure 2. The study area displaying the MTBS raster data used over the time span of 33 years (Butcher 2018).

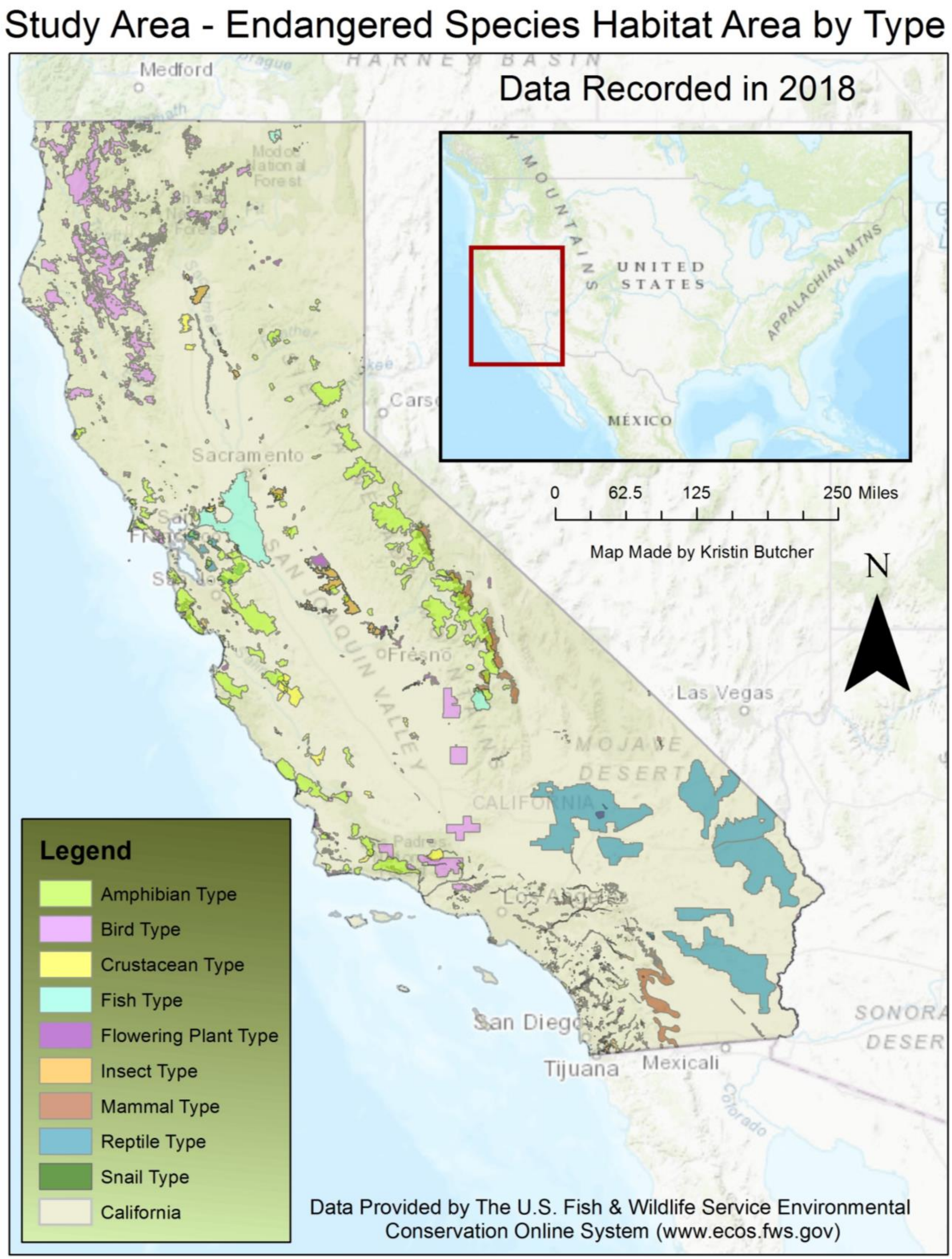

Figure 3. The study area displaying ES and TS critical habitat data organized by the wildlife classification system TESS used for the GIS macro analysis (Butcher 2018)

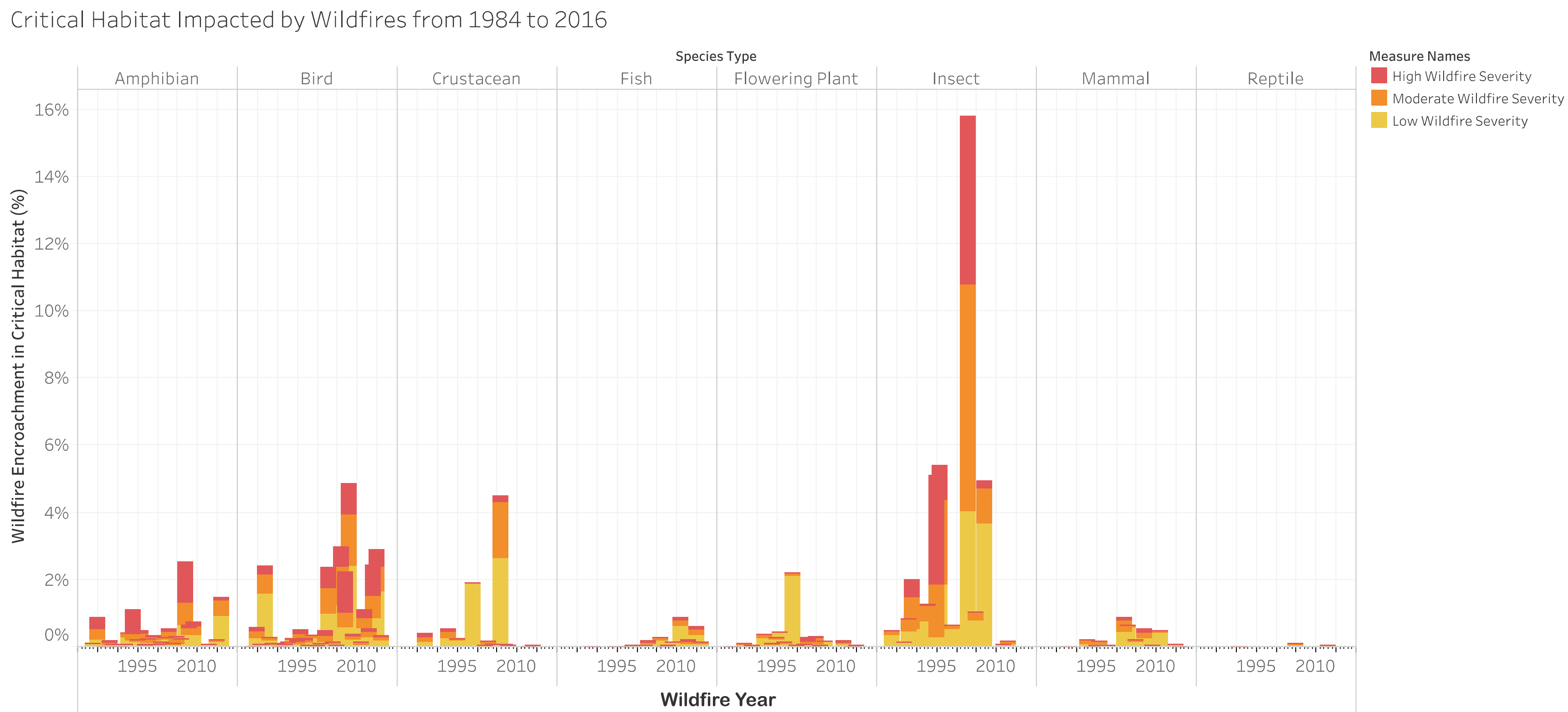

Figure 4. Data displaying the percentage of ES and TS critical habitat organized by TESS wildlife group impacted by wildfire (Butcher 2019).

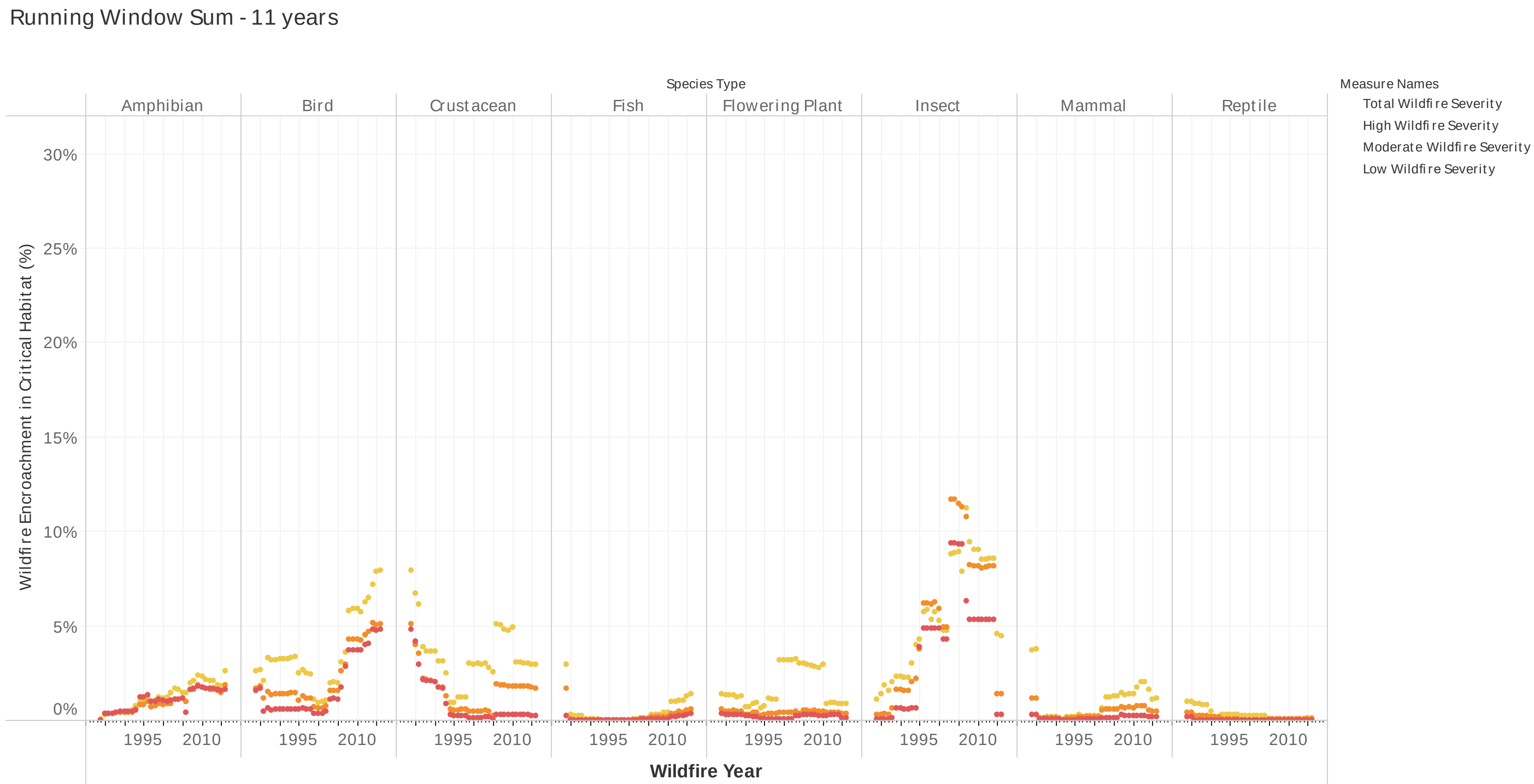

Figure 5. A running window sum analysis performed to define trends in data to determine the wildlife group that is most impacted by wildfire encroachment (Butcher 2019). The running window sum analysis was performed using Tableau Software using a span of 11 years.

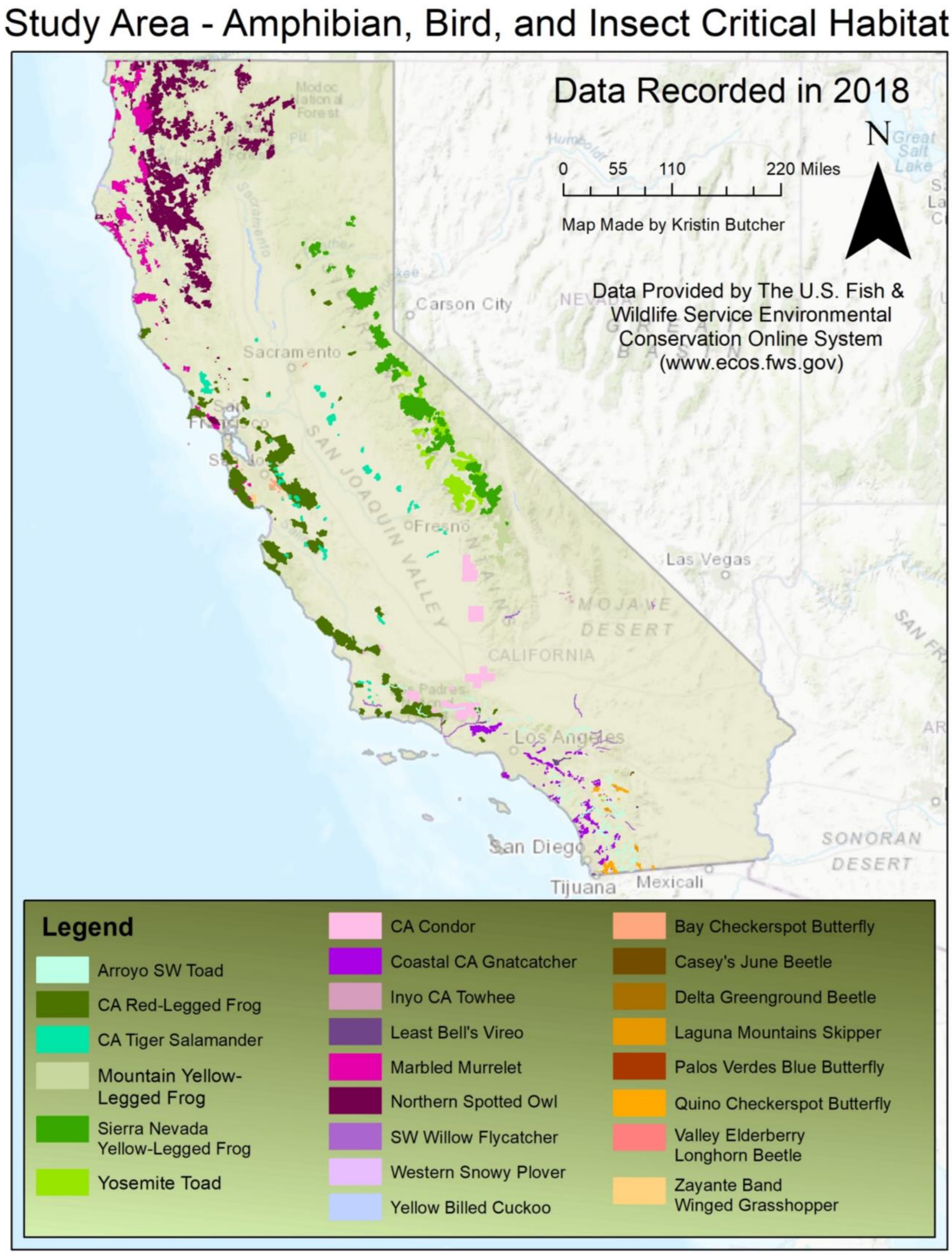

Figure 6. The study area displaying individual amphibian, bird and insect ES and TS critical habitat data used for the GIS micro analysis (Butcher 2019)

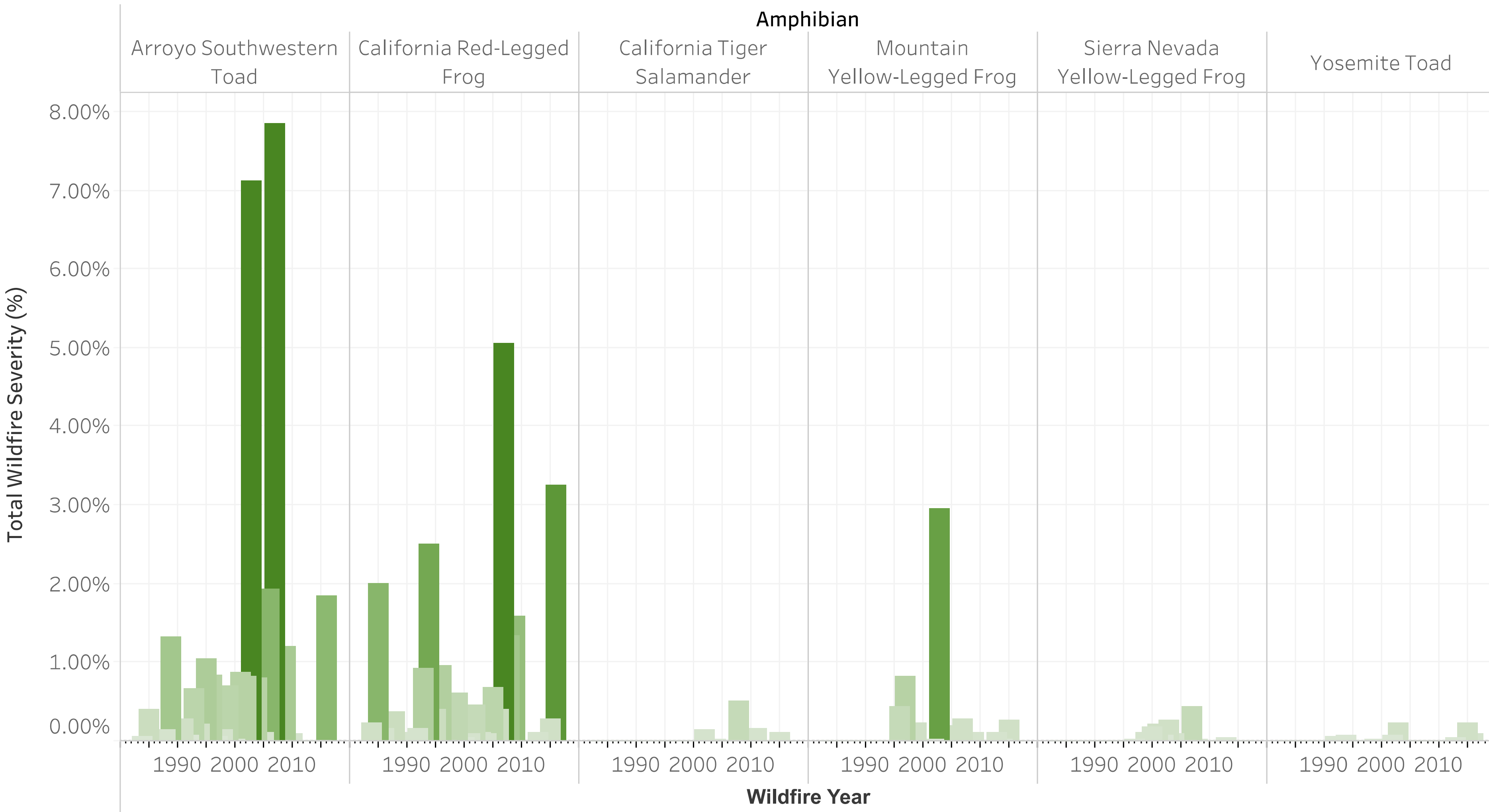

Figure 7. Data displaying individual amphibian ES and TS critical habitat most impacted by wildfires (Butcher 2019).

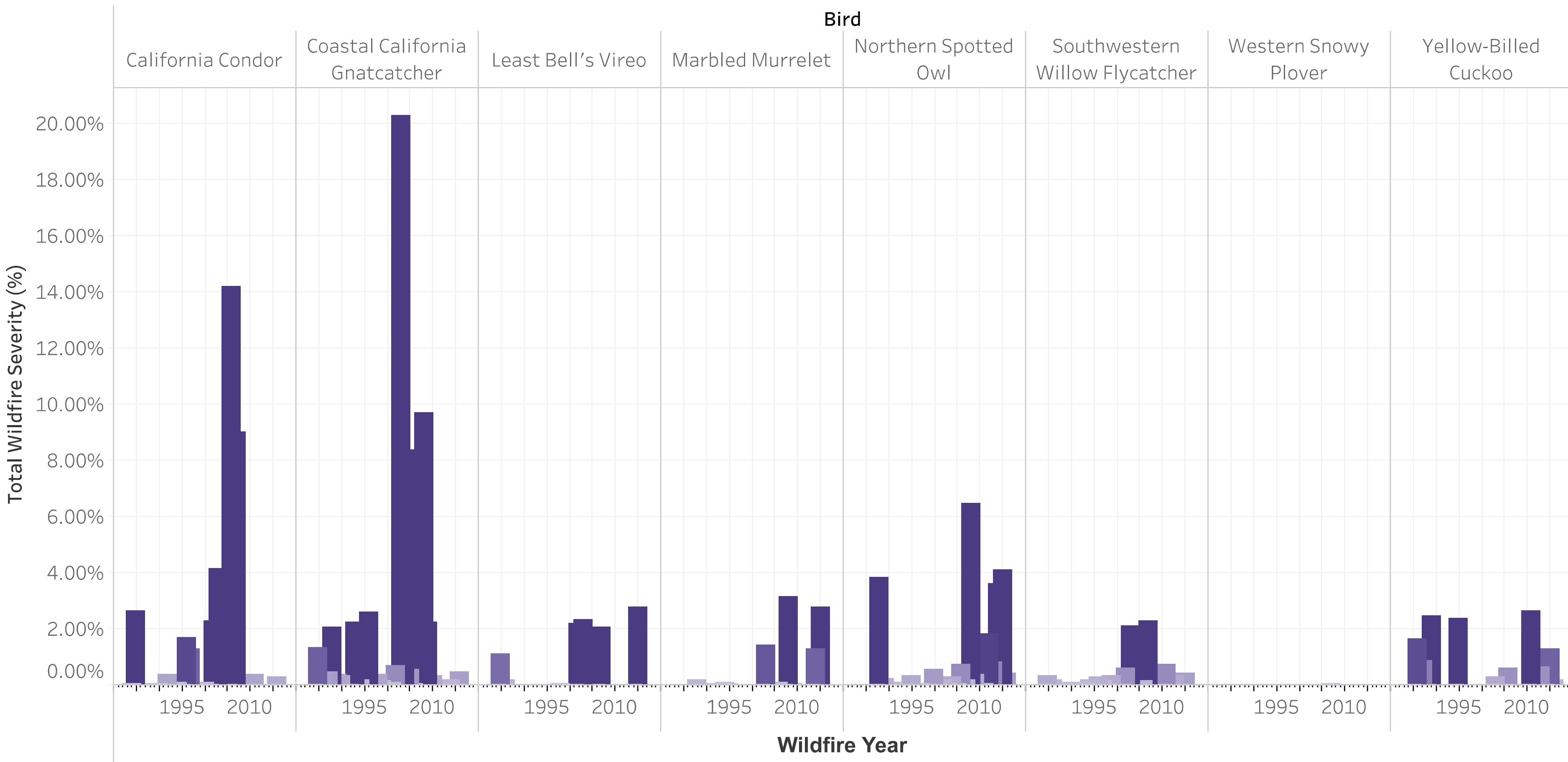

Figure 8. Data displaying individual bird ES and TS critical habitat most impacted by wildfires (Butcher 2019).

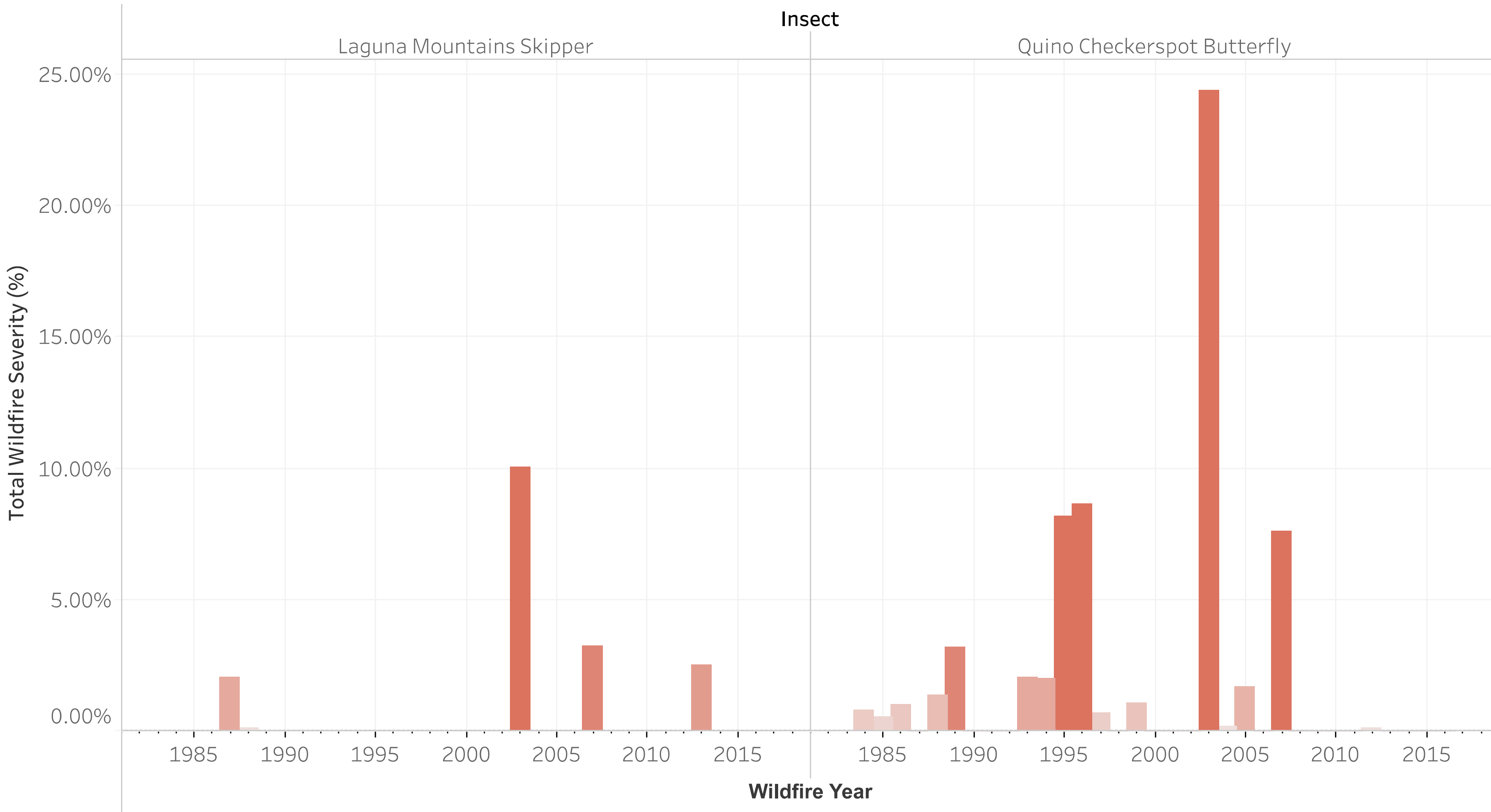

Figure 9. Data displaying individual insect ES and TS critical habitat most impacted by wildfires (Butcher 2019).