Spring 5-23-2020

The relationship between forest fires and forest dynamics in California's North Coast Bioregion: How altered fire regimes have affected the vegetative outcomes of oak woodlands and mixed conifer forests

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This Master's Project

The relationship between forest fires and forest dynamics in California's North Coast Bioregion: How altered fire regimes have affected the vegetative outcomes of oak woodlands and mixed conifer forests

by

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is submitted in partial fulfillment of the requirements

for the degree of:

Master of Science

in

Environmental Management

at the

University of San Francisco

Submitted:	Received:
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Max Bencomo Date	Stephanie Siehr, Ph.D. Date

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ABSTRACT

Wildfire is a necessary part of ecosystem function in California, but fire suppression and the spread of invasive species have endangered many ecosystems. The North Coast bioregion of California has seen dramatic shifts in forest ecology and vegetative density, largely due to the disruption of historic fire regimes. Historic fire regimes were previously maintained through indigenous land management, but the arrival of European settlers in the 1850's initiated the changes reflected in current fire regimes. Not only is the North Coast bioregion the hotbed of recent fire activity, it is experiencing decreased counts of heterogeneity within forests while also seeing increased amounts of fuel loads that contribute to more severe fires. This paper utilizes a comparative analysis of mixed conifer forest and oak woodland ecozones, describing the vegetative outcomes of their altered fire regimes. Through the synthesis of case studies, government reports, impact assessments, and management plans, I investigated the current state of these landscapes and developed recommendations for future management. The combination of fire suppression and increasing invasive populations have led to numerous shifts in forest systems. Invasive species heavily influence forest fuel loads and can change ecosystem structure, which can subsequently alter the area's fire regime. Once a fire regime has changed it can imperil the livelihood of historic plant populations. Conifer forests are seeing shifts from resilient species to more fire-sensitive species, which can lead to the decimation of entire populations by high-severity fires. Oak woodlands are also suffering from fire regime changes, as conifers are encroaching and overtaking the forest canopy, drowning out oaks and reducing them to shrub species. Both mixed conifer forests and oak woodlands are threatened by changes in their respective fire regimes. These shifts in vegetation patterns can be amended through integrative management initiatives, notably the application of prescribed burns to aid the restoration of historical fire regimes.

1. Introduction

Fire is an essential element of California's natural composition. Fire is necessary for the maintenance of ecosystems and often the driver of biotic successions; without it very few of our native ecosystems would exist as they do today. Fire helps promote complexity within already complex systems and offers vegetative communities the opportunity to reset their structures through the recycling of nutrients and regulation of biodiversity. Native Americans were the most frequent form of fire ignition in northwestern California, initiating burn patterns that resulted in alterations in vegetative arrangements and ecosystem dynamics (Lewis, 1993, Keeley, 2002). As a physical process, fire has direct and indirect effects that stretch far beyond the immediate area it burns; the production of heat, the rate of spread, and its interaction with water, air, and plant species are all a part of the widespread ecological properties that carry on after the smoke has cleared.

Particular interactions emerge as the new exposure to sun, space, and nutrients bring about opportunity for invasive species to settle. The spread of invasive species is considered one of the greatest threats to natural communities (Mack & D'Antonio, 1998). Just like fire can transform a landscape, the unmitigated spread of invasive plants can remove an ecosystem from its previous balance and install a new order to plant communities. By definition, invasive species or exotic species are non-native species that can cause changes in ecology and potential harms to a biotic community. While the impacts of particular invasive species' can be quite variable, there is a general consensus among the scientific community of the long-term implications and many management concerns bound to their spread in natural areas.

Areas of disturbance, such as recent burn zones, are often exploited by invasive species as there is little competition for water and nutrients. Additionally, many exotic species are able to out-compete native species due to their ability to grow rapidly and take over large swaths of ground, crowding out existing plants before they have a chance to develop. The diminishment of native species thus reduces the interactions with biodiversity, potentially disrupting the ecological balance and interrupting the connectivity of local ecosystem relationships. With the world's biodiversity increasingly under threat, the alteration of ecological connections and ecosystem balances by invasive species marks an immediate and long-term threat to preservation and management (Harty, 1986, Gordon,1998).

Invasive species are not the only plants that make undesirable appearances in other biotic communities, as the competition for sun, space, and resources is not limited to interactions between native and exotic species. The encroachment of native species is a critical issue, and one that has been exacerbated by the disruption of historic fire regimes. In some portions of the of the state these ecosystem struggles have resulted in greatly diminished populations of keystone biomes such as the California oak woodlands. In the case of the oak woodlands, native conifers such as Douglas fir (Psuedotsuga menziesii) have wreaked havoc on native oak populations, invading oak habitat and reducing oak numbers by outgrowing the lengthy, but low oaks. Though efforts to slow or reverse the changing of these landscapes are underway it is concerning that a positive-feedback loop may already be in place regarding the ecosystem's relationship with fire. Encroached oak woodlands no longer benefit from the existence of past fire regimes as their subdued state has left them susceptible to the low severity burns that once protected them. Yet, their liberation may come in the form of severe wildfire exposure, a complex conundrum unto itself that will be explored in the management portion of this paper.

Such shifts in canopy dominance have been heavily influenced by the altered ecosystem interactions with fire and will likely continue to at an increasing pace. There is much research concluding that invasive species can alter an ecosystem's fire regime, but less analysis focused on the effects of native ecosystem shifts and resulting fire dynamics. With the increasing abundance of species displacement by native and invasive species, we are presented with extensive plant composition changes, bringing about alterations in ecological processes and fire regimes (D'Antonio, 2000). Combining these troubling trends with a fire management strategy revolving around fire suppression, the situation becomes more desperate. As we continue to reduce and restrict fire on the environment, we further remove that ecosystem from its historic fire regime, altering the ways the biotic community interacts with fire.

Seeing as the past three years have brought highly destructive fire counts to the North Coast bioregion, much more needs to be done in terms of research devoted to these areas. According to CalFire (2019), total counts from the past three fire seasons have burned over 650,000 acres in North Coast bioregion: Kincaide Fire 2019 (77,758 acres), Mendocino Complex 2018 (459,123 acres), Tubbs Fire 2017 (36,807 acres), Nuns Fire 2017 (34,398 acres), Atlas Fire 2017 (51, 624 acres). That is over 650,000 acres available for potential exotic plant invasions and species shifts to take place, much of it occurring long before any vegetation remediation will take place. In the state of California alone the past 200 years have led to over 1,300 introduced exotic plant species (Rejmanek and Randall, 1994). This statistic coupled with California's propensity for fire prevention have created very challenging and concerning management situations.

In terms of the management of invasive populations in burn scars, the best practice might be fighting fire with fire. Prescribed burns are utilized quite often when dealing with invasive plant populations (Randall et al., 1998, DiTomaso and Johnso, 2006, Potts and Stevens, 2009, Alba et al., 2015). There are a number of cases in which prescribed burns may increase exotic populations and thus hasten the expansion of those invasive species; however, there are also numerous instances in which fire alone will decrease the number of invasives present. Therefore, the knowledge of the existing ecosystem's fire regime is paramount prior to the application of prescribed burns (Pyke et al., 2010, Brooks and Lusk, 2016). Mastication is another method often utilized to reduce fuel loads and diminish invasive populations, but similarly, the complexity of the ecosystem can make the application of this method quite challenging. While each of these techniques have their downsides, they do offer solutions in most scenarios, and when paired with integrative management approaches can achieve high rates of success.

Climate change is expected to lead to proliferated sequences of events for vegetation and landscape (Wagtendonk et al., 2018). The likely occurrence of temperatures rising with unknown precipitation patterns (Lenihan et al., 2008) leads to very volatile ecosystem conditions and reactive fire regimes. Forest fuel loads and local weather will see both the direct and indirect effects of climate change as the build-up of fuel loads creates the increased risk of high severity fires. Many of the future climate and fire models agree that climate change will lead to increases in fire frequency and size across the western United States (Lenihan et al., 2008, Safford et al., 2012, Westerling, 2016). The reestablishment of historic fire regimes needs decisive action. As the content of this paper's findings and discussions are not restricted to the North Coast bioregion it is my hope is that the larger scope elevates the urgency and necessity in addressing the vegetation shifts and management concerns examined in this paper.

1.1 Research Questions

How are altered fire regimes affecting the vegetative makeup of oak woodlands and mixed conifer forests in the North Coast bioregion?

To carry out this exploration, I addressed three questions:

1. Are invasive species an immediate threat to oak woodlands and mixed conifer forests and has fire suppression increased invasive populations?
2. How does fire severity affect the revegetation of oak woodlands and mixed conifer forests?
3. What are the best management options for oak woodlands and mixed conifer forests regarding their interactions with invasive species and altered fire regimes?

1.2 Methods

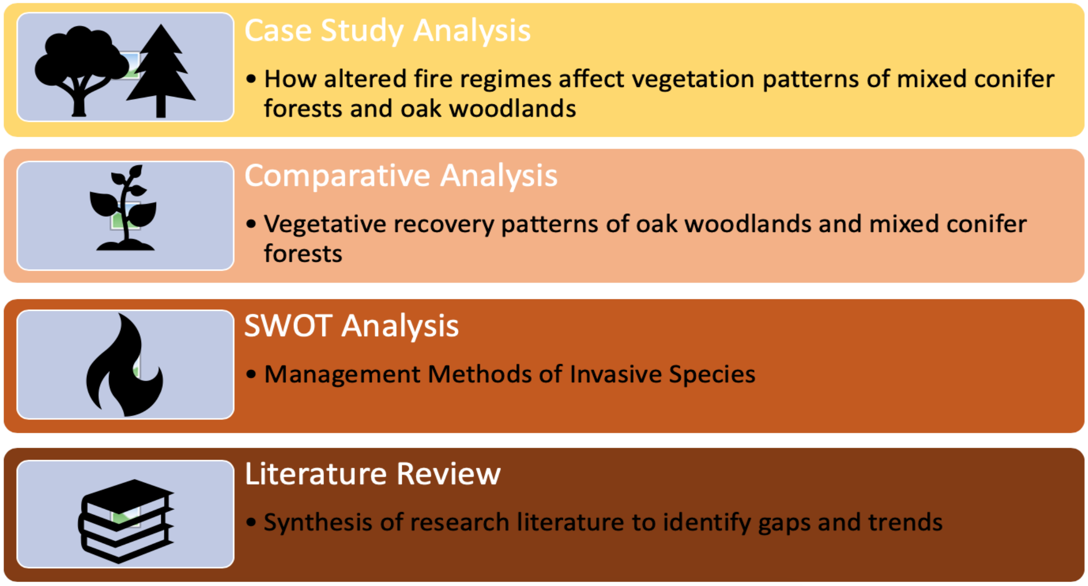


Figure 1: Research Methods (Author)

The purpose of this paper is to detail the vegetation responses of oak woodlands and mixed conifer forests post-wildfire, and how altered fire regimes are affecting the ecological structure of these ecozones.

Over the course of this paper I will often make reference to the historic fire regime of an area, and by this I am referring to the fire regimes in place prior to European settlement in California, which occurred around 1850. As another note, I will use both of the words "ecosystem" and "ecozone" to describe the characteristics of oak woodlands and mixed conifer forests. Both words entail the mix of biotic community interaction and their physical environments, and thus will be used interchangeably. Likewise, bioregion will only refer to the North Coast bioregion, the geographic area and landscape defined by Miles and Goudey (1997).

In an effort to collect as much pertinent material on these two ecozones as possible, I made the decision to include studies from areas outside of the North Coast bioregion. One reason was due to the minimal amount of research within the bioregion boundaries. Despite the devastating fire activity that the bioregion has experienced in the past three years, there is a definite need for more research in these areas.

I expanded my search to include studies of conifer forests and oak woodlands located in similar climates and with comparable vegetative representation. In doing so, I was able to produce a much more detailed analysis of these ecozones and elaborate further on the current complications being experienced due to altered fire regimes. Though many of the reports I cite are from studies outside of the North Coast bioregion, I only applied findings involving species that could be found within the North Coast bioregion. Similar parameters were applied in regard to elevation and climate, as I did not want to misrepresent the management portion by advocating recommendations from an unrelated ecosystem.

The management recommendations were primarily based on the findings of the following studies:

Table 1: Key studies in determining management recommendations (Author)

Invasive Species	Oak Woodlands	Mixed-Conifer forests
Fire Management and Invasive Plants: A Handbook – US Fish and Wildlife Service (Brooks and Lusk. 2008)	**Do repeated wildfires promote restoration of oak woodlands in mixed-conifer landscapes? (Nemens et al. 2018)**	**Predicting conifer establishment post wildfire in mixed conifer forests of the North American Mediterranean-climate zone. (Welch et al. 2018)**
Control of Invasive Weeds with Prescribed Burning (DiTomasio et al. 2006)	**Conifer encroachment in California oak woodlands. (Cocking et al. 2015)**	**Impact of a high-intensity fire on mixed evergreen and mixed conifer forests in the peninsular ranges of Southern California, USA. (Franklin et al. 2006)**
The use of fire as a tool for controlling invasive plants (DiTomasio et al. 2006)	**California black oak responses to fire severity and native conifer encroachment in the Klamath mountains. (Cocking et al. 2012)**	**How does forest recovery following moderate-severity fire influence effects of subsequent wildfire in mixed-conifer forests? (Collins et al. 2018)**

1.2.1 Case Study Analysis

The basis of my research was conducted through case study analysis, interpreting the findings of related research studies and applying those findings to answer my own research questions. The thoroughness and detail that the studies were able to achieve greatly benefitted my analysis and often led to exploration of similar studies utilized within the one I was analyzing. This format also aided in utilizing content outside of the North Coast bioregion, allowing me to find specific ecosystems with the correct vegetation representation that I could apply to my own investigations. One such example was in Franklin et al. (2006) which detailed the devastation of conifer forests following a severe wildfire in San Diego County. Typically, one might not associate San Diego climate and vegetation an accurate representation of the North Coast bioregion, but the specificity of the landscape and intention of the study allowed it to have a great influence on my findings. The individuality of each of these case studies offers valuable insights into the particularities of their research and the opportunity to apply their findings to similar environments.

1.2.2 Comparative Analysis

In addition, I used a comparative analysis to discern the vegetative recovery patterns of oak woodlands from mixed conifer forests and to understand how those patterns have come to be. These two ecozones were selected for study because they represent a large portion of the vegetation burned by the recent wildfires that occurred in the North Coast bioregion. I chose to investigate the vegetative trends and forest dynamics that were occurring within these two ecosystems because they represent a significant portion of the region's ecological makeup, and thus heavily influence the bioregion's ecology. This method was particularly helpful in the response to high-severity fires, seeing the two ecozones exhibiting very different outcomes to similar fire patterns. The comparative analysis also helped establish the general characteristics of oak woodlands and mixed conifer forests, allowing simpler identification of fire regimen trends and vegetative expectations. In understanding how the historic regimes operated I was able to identify more likely scenarios of what's to come, both in terms of vegetative response and necessary management applications.

1.2.3 SWOT Analysis

I also utilized a SWOT analysis when detailing the management recommendations of invasive species, finding considerable differences between prescribed burns and mastication. The SWOT analysis identifies the strengths, weaknesses, opportunities, and threats of the application, offering an encompassing look at method in consideration. Through this lens I was able to identify the drawbacks of mastication in these ecozones and come to regard it as a secondary strategy more adept at accomplishing fuel reduction than invasive species removal. It was also helpful in assembling findings from different studies into a unified location, which gave me a clearer view of which recommendations were most appropriate within the targeted ecozones.

1.2.4 Literature Review

Fire is essential to the maintenance of many ecosystems in California. Many historic fire regimes in California have been altered due to fire exclusion (Skinner et al., 2018, Coppletta et al., 2019). Invasive plants can also pose a threat to fire regime change (D'Antonio and Mack, 1998, D'Antonio, 2000, Keeley, 2001, Brooks et al., 2004, Brooks and Lusk, 2008, Keeley et al., 2011). Oak woodlands are more susceptible to invasive species than mixed conifer forests due to their open nature, lower elevation range, and closer proximity to grasslands (McDonald, 1980, Klinger et al., 2006, Klinger et al., 2009, Klinger et al., 2011).

In terms of invasive management, mastication and prescribed burnings are the most commonly referenced methods in oak woodlands and mixed conifer forests. Mastication offers increases in vegetative growth; however, the populations that the technique propels may be both native and non-native species (Potts et al., 2009, Owens et al., 2015, Wilkin et al., 2017). While mastication has limited effectiveness in terms of invasive management, prescribed burns tend to be much more successful (DiTomasio et al., 2006, Pyke et al., 2010, Alba et al., 2015). Prescribed burnings can be very effective at decreasing annual populations especially those with short-lived seedbanks (DiTomasio et al., 1999, DiTomasio et al., 2006, Brooks et al., 2016). Multiple burnings will likely be necessary as a single application will likely reduce, but not eradicate invasive populations (DiTomasio et al., 1999, DiTomasio et al., 2006, Brooks and Lusk, 2008).

Conifer populations are suffering from greater exposure to high-severity fires due to fire regime changes (Franklin et al., 2006, Welch et al., 2016, Collins et al., 2018). One factor is their inability to provide sufficient regenerative counts following high-severity fires (Franklin et al., 2006, Welch et al., 2016, Collins et al., 2018). Mixed conifer forests are also suffering from shifts in speciation with the emergence of higher populations of shade-tolerant, but fire-sensitive species (Franklin et al., 2006, Welch et al., 2016, Steel et al., 2017). The combination of these two factors can lead to devastating effects on conifer forests if exposed to high-severity fire (Franklin et al., 2006, Welch et al., 2016, Collins et al., 2018). Conifer management should be centered on reintroducing low to moderate-severity fires which can quickly reduce forest fuel loads (Franklin et al., 2006, Welch et al., 2016, Collins et al., 2018). Reseeding efforts will likely be necessary to combat the low regeneration rates afforded by the high fire severity (Franklin et al., 2006, Welch et al., 2016)

Oak woodlands rely on fire to help maintain their open nature but can become vulnerable to conifer encroachment once the element of fire is removed from the landscape (Hunter and Barbour, 2001, Cocking et al., 2012, Cocking et al., 2014, Cocking et al., 2015, Nemens et al., 2018). The four stages of conifer encroachment are establishment, piercing, overtopping, and decadent (Cocking et al., 2014, Cocking et al., 2015). A single high-severity wildfire can begin to re-establish oaks as the dominant canopy species in areas formerly encroached by conifers (Cocking et al., 2014, Cocking et al., 2015, Nemens et al., 2018). Continued fire exposure is necessary in maintaining the oak dominance as this will reduce conifer sprouts and allow oaks ample time to restore woodland habitat (Cocking et al., 2015, Nemens et al., 2018). High-severity fires are very difficult for land managers to replicate, though severe fire may be the only mechanism to provide such widespread results (Cocking et al., 2014, Cocking et al., 2015, Nemens et al., 2018)

2. Background

2.1 Designation of Bioregion & Climate

For the purposes of this report, the area of study is within the North Coast Ranges ecological zone as identified in the Ecological Subregions of California report (Miles and Goudey, 1997). This zone begins at the southern-most tip of Marin County and follows the coastline up past Crescent City to the Oregon border with its eastern edges running along Napa, Lake, and Mendocino counties, before skirting the western edge of Trinity County and narrowing upwards as it continues into Humboldt and finally Del Norte County (Figure 2). This bioregion features a high amount of topographical diversity, seeing elevations vary from sea-level to 3,000ft in the coastal sections and over 8,000ft in the interior Northern Coastal Ranges (Miles and Goudey, 1997).

Figure 2: Map of California Ecological Zones, as defined by Miles and Goudey. Taken from *Fire in California Ecosystems* (Van Wagtendonk et al., 2018)

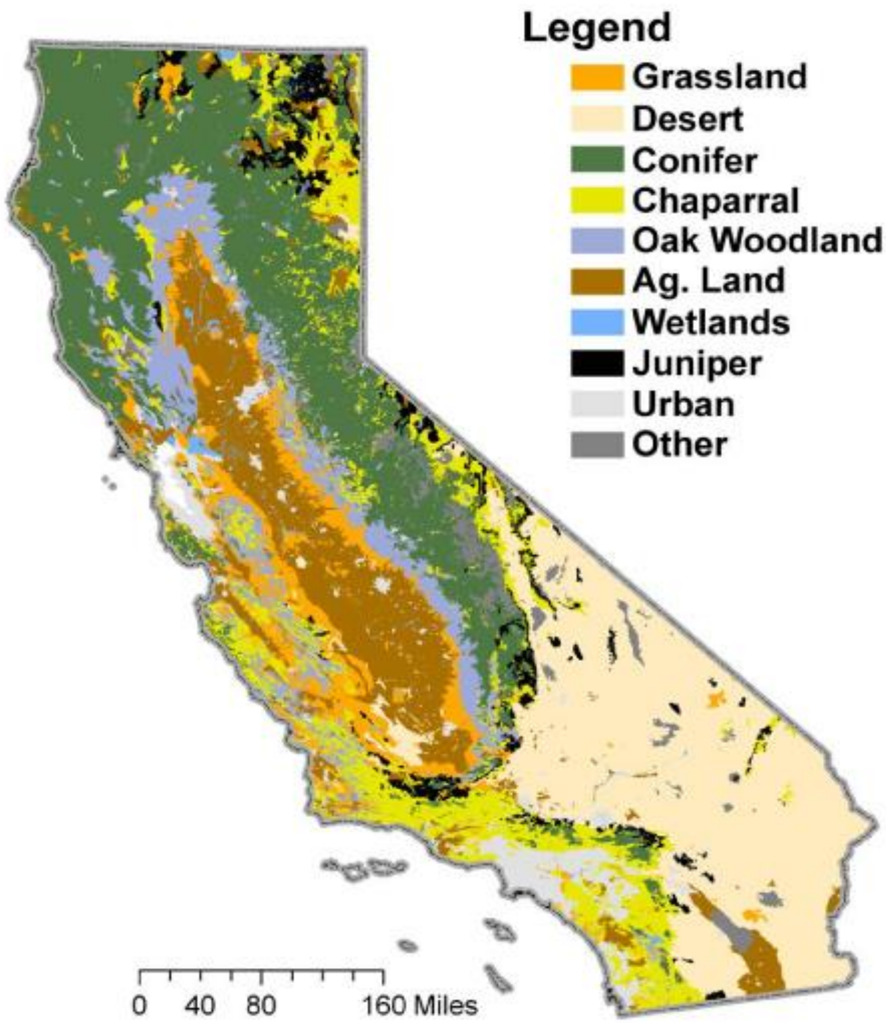


Figure 3: California Biomes
(AP Environmental Science)

From a climatic perspective, while experiencing the same Mediterranean climate as much of the state, there is great variance in precipitation and temperature throughout the North Coastal zone. "The North American Mediterranean-climate zone (NAMCZ) supports the highest precipitation variability in North America and a 4 to 6-month annual drought and has seen greater-than-average increases in air temperature and fire activity over the last three decades" (Welch et al., 2016). The Mediterranean climate is primed for fire interactions, as its prolonged growing season also denies the ability for plant material to decompose properly, lending large amounts of dry debris to be consumed by combustion (Sugihara et al., 2018). Temperatures increase and precipitation typically decrease as you head south from the Oregon border, with precipitation totals ranging from 20 inches to 118 inches annually (Miles and Goudey, 1997). Mountain ranges play a key part in precipitation distribution primarily due to the prevailing winds and orographic enhancement, prompting greater amounts on the western slopes and lower totals on the leeward side. Summer fog is vital to the livelihood of much of the ecosystems within the region, maintaining soil moisture levels and reducing plant stress in an otherwise lengthy warm and dry period (Dawson, 1998).

2.2 History of Northern California Coastal Wildfires

Historical fire studies of the last 1,000 years show a great deal of variance among fire patterns of northwestern California (Van Wagtendonk et al., 2018). Native Americans were the primary source of fires in the region, conducting annual burnings with regular frequency in grasslands and oak woodlands (Lewis, 1993). Prescribed fires tended to occur near settlements, with more frequent burnings occurring next to villages or sources of food or materials. While lightning fires were less common, they did occur, and were much more frequent in the mountain ranges than the surrounding valleys and coastal regions.

The early - mid 18th century saw a number of changes to the region's relationship with fire. Fort Ross (Sonoma County) was established as a Russian–American outpost and the primary entry-point for traders and settlers. Consequently, the burning practices of Native Americans greatly diminished. The influx of colonizers pushed Native American communities further and further from their settlements, as they contended with the disease and violence brought upon by the settlers (Van Wagtendonk et al., 2018).

With the introduction of the Euro-Americans also came the exposure to cattle and ranching, which had drastic effects on the region's ecology and fire regime. Settlers converted large sections of forests and woodlands to expand grassland and prairie habitat for their increasing cattle and sheep stocks, cutting down trees and planting grass seeds to expand foraging territory (Barrett, 1935). The mid 19th century brought about heavy ranching and the introduction of logging. A new type of burning became prevalent as the logging industry grew; felled forests were burned as an act of precaution against potential fuel loads and to create greater access for timber extraction. With the early 1900's seeing increased American industrialization, material demands quickly took hold of forests and wildlands. The government saw the protection of these resources as paramount, and in 1905, with the promotion of the United States Forest Service, the era of fire suppression began (Keter, 1995).

2.3 Ecoregions of study: Oak Woodlands and Mixed Conifer Forests

Oak woodlands are a hallmark of the Californian landscape. Oak populations stretch across the entirety of the state and beyond, with their northernmost extent reaching into British Columbia (Little, 1971). Versatile in both ecological makeup and geographic range, these woodlands are often found as divisional zones, transitioning into conifer forests in higher elevations and prairie grasslands in the valleys below. Within the North Coast bioregion, they are typically found in the warmer and drier areas, either interspersed with other trees or covering grasslands and savannah as the sole tree species (Wagtendonk et al., 2018).

Common canopy species of oak woodlands are Coast Live oak (Quercus agrifolia), Oregon oaks (Quercus garryana), California black oaks (Quercus kelloggii), Valley oaks (Quercus lobate), California bay (Umbellularia californica), Pacific madrone (Arbutus menziesii), and Douglas fir (Pseudotsuga menziesii) (Figure 4). While these trees may dominate the height class of oak woodlands, there are many lower-lying shrub and sub-shrub species to be found below. Commonly found species are Sticky Monkey Flower (Diplacus aurantiacus), Mugwort (Artemesia douglasiana), Poison Oak (Toxicodendron diversilobum), Pacific blackberry (Rubus ursinus), Arroyo Lupine (Lupinus succulentus), and Manzanitas (Arctostaphylos). Valley oaks are usually found in lower elevations and near riparian areas as they require year-round access to groundwater while Oregon oaks and Californian black oaks can be found near mid-higher elevations.

Figure 4: Visual key of common oak species within North Coast bioregion. Variations in size and shape of leaves and acorns are often most useful in identification. (CNPS, 2019)

Oaks are often considered the most important genus in California due to its wide use by wildlife as a source of food and cover in forest and rangelands (Tevis, 1952, Edelbrook, 1991, Long et al., 2016). The California black oak in particular is important due to maintaining greatest range size, having the largest acorns of all western oaks, and the relationship it has with the parasitic Pacific mistletoe that produces berries that are heavily relied upon by birds and small mammals (Bolsinger, 1988, Garrison et al., 2002).

Like oak woodlands, mixed conifer forests have a wide distribution throughout the North Coast bioregion. And similarly, like oak woodlands, they can be made up of many different species. Incense cedar (Calocedrus decurrens), Douglas fir (Psuedotsuga menziesii), Tanoak (Notholithocarpus densiflorus), Sugar Pine (Pinus lambertiana), Ponderosa pine (Pinus ponderosa), White fir (Abies concolor), Western Hemlock (Tsuga heteriphylla), Pacific Madrone (Arbutus menziesii), and Big Leaf Maple (Acer macrophyllum) (Figure 5).

The dominance of broadleaf trees and conifers can leave the ground level exposed to pockets of sunlight, as the conifers maintain their needles while the broadleaf species such as maples and oaks shed their leaves each Fall. Meanwhile, the few shade tolerant species likely have little competition for the lower to mid forest tiers, but there are lower counts of shrubbery than oak woodlands due to the decreased sunlight availability. Many tree species within mixed conifer forests are shade intolerant, therefor creating a constant fluctuation in dominance. Mature forests are typically heavily wooded with dappled sunlight, while younger portions or edge arrangements tend to be interspersed with larger gaps or sunny clearings. The densest forest portions will likely be found on north-facing slopes and lower hillsides such as canyon bottoms. Unlike oak forests, mixed conifer forests can be found at much higher elevations, and it is not uncommon to find conifer species above 8,000ft (US Forest Service, 2012).

The needles of conifers fulfil the same roles as leaves do, capturing sunlight and taking in carbon dioxide to expel oxygen, with the added bonus of staying on the tree and taking in sunlight throughout the year. The needles also provide a number of specific benefits for surviving in harsh climates and competitive conditions. The waxy coating of the needles allows the tree to retain more water than that of a regular leaf and also make them difficult and distasteful for insects to eat. Since mixed conifer forests tend to thrive in montane areas the needles have developed to survive freezes and snow, and their shape makes the trees more aerodynamic and able to withstand high winds.

Figure 5: Examples of conifer needles. Douglas fir, blue spruce, ponderosa pine, and coastal redwood (from left to right) (https://www.growforagecookferment.com/foraging-for-pine-needles/)

3

3.1 Fire Regimes

The effects of a single fire on an ecosystem are typically clear to see and relatively easy to analyze. Yet when considering fire as an ecological process you must account for a number of factors including the pattern of effects over time, multiple fire events, and the subsequent changes in ecosystem properties. It is through this mold that we define the concept of fire regimes. As stated in Fire in California's Ecosystems (Wagtendonk et al., 2018) "Fire regimes are a convenient and useful way to classify, describe, and categorize the pattern of fire occurrence for scientific and management purposes".

Fire regimes are usually appointed to a given ecosystem through a combination of vegetation type and land area; however, these regimes may vary within the same plot or vegetation type as changes occur within the space. An area could undergo a number of classifications over a 20-30-year period as the ecosystem goes through alterations of natural and unnatural sources such as logging, landslides, fire damage, invasive species encroachment, insect infestation damages, etc.

As with most classification systems there is a level of oversimplification involved, and the proper classification of each fire regime should be representative of that specific area and its ecosystem properties. Famed forest ecologist Miron Heinselman created a classification system in 1981 that has served as the foundation of fire regime categorization. It distinguishes seven different fire regimes comprised of three primary categories: (1) the fire type and intensity, (2) the size of typically ecologically significant fires, and (3) the fire frequency/ fire return interval (Wagtendonk et al., 2018) (Table 2).

The two most important aspects to defining a fire regime are the ecology or vegetation of the area, and the climate. Heinselman (1981) found that the western states featured very complex fire relationships due to the variation in topography, vegetation, and climate. California can be particularly difficult to define because of the multiple fire regimes that may exist due to the different fire types that can burn at multiple frequencies under very diverse weather conditions. Kilgore (1981) wrote about the many variations that need to be accounted for when considering the fire regimes of western forests. The composition and structure of vegetation are determined by climate, fire intensity, and fire frequency, and in turn, fire frequency and fire intensity are determined by the climate, vegetation structure, and topography. The interconnectedness of forest ecology may be cliched, but its role is clearly demonstrated when fire is introduced into the equation.

Heinselman's fire regime model was further expanded upon by Hardy et al. (2001) by replacing the types of fire with three levels of fire frequency and three levels of severity. This classification became the basis of determining a natural fire regime through five condition classes, thus enhancing the role fire severity has on the ecological landscape (Table 2).

Table 2: Heinselman's fire regime groups, as modified by Hardy et al., (2001). (Author) adapted from Sugihara et al. 2018

Fire Regime Group	Fire Frequency	Fire Severity	Severity notes
1	0-35 years	Low to Mixed	Surface fires are common, little vegetation replacement
2	0-35 years	High	Severe fires, with replacement of over 75% of overstory
3	35-100+ years	Mixed	Mixed severity with some low-severity burns
4	35-100 years	High	Severe fires, stand replacement common
5	200+ years	High	Severe fires, stand replacement expected

Given the complexity of fire and its effects on a specific ecosystem, fire regime has been broken down into three primary categories based on certain attributes. The first of mention, **temporal attributes,** involves the seasonality of fire and the fire return interval.

The seasonality of the burn can play a key role on the resultant effects on the ecosystem and vegetative recovery. Since California has numerous plant species with specific seasonality adaptations, the subsequent vegetative distribution will be largely dependent on the time of year that the burn has occurred. The North Coast bioregion typically features Summer-Fall fire season with the majority of the fires occurring during the months of July through October. Despite California having fairly predictable seasonal weather, the timing and severity of the fire can be based on many other factors including topography, ignition sources, and vegetative characteristics. Given these additional influences and the likelihood of vegetative shifts, it is imperative that the probability of a repeated fire event is investigated, thus prompting the designation of fire return interval.

Fire return interval is related to fire cycle and fire rotation but can simply be defined as the length of time between fires on a particular area of land (Wagtendonk et al., 2018). Many plant species are unable to cope with fire damage if fires occur too frequently or too infrequently, or if the fire comes too early in a season. Thus, the aim of the fire return interval is to accurately define ecosystem characteristics and vegetative response to fire to highlight the vulnerabilities and resiliencies of that ecosystem.

Oak woodlands have a *truncated short fire return interval* which typically sees the area burn routinely over shorter periods of time, with an average mean of a surface fire occurring every 10 years. Longer periods without fire may allow the encroachment and establishment of other species that do not rely on fire to repopulate or maintain dominance. This return interval only experiences large, severe fires capable of replacing entire stands once every 120 years (USDA). Mixed conifer forests have a *short fire return interval,* meaning most of the area experiences a relatively frequent fires, but with the potential for some portions to undergo lengthier periods without fire. This allows for the forest to maintain its open spaces and only sees full stand replacement from fire every 200-250 years (USDA).

Spatial attributes of fire regimes involve the fire size and the spatial complexity of the fire. While fire size is fairly straight-forward in its definition of the total area within the fire perimeter, there are four categories of which the size can fall under. Both oak woodlands and mixed conifer forests tend to experience *large fire size* due to their continuous distribution of fuels and extensive coverage over large areas.

Spatial complexity can be introduced as the variability of severity within a fire's perimeter. This can be attributed to many different factors including the slope, vegetation density, fire history, and topography. Oak woodlands usually fit within the low spatial complexity, giving a fairly even spread of the fire with few unburned spaces. Mixed conifer forests of the North Coast bioregion would fall under moderate spatial complexity given the variance in terrain, access to moisture, and types of vegetation present.

Within the realm of **magnitude attributes** are fireline intensity, fire severity, and fire type. Fireline intensity acts as a measurement of how much energy is released per the length of the fire. This can be illustrated through the example of a grassland burning with higher energy release during windy conditions vs burning with a lower intensity if little to no wind is present. Both oak woodlands and mixed conifer forests would fall under the category of low fireline intensity largely due to the frequency of which these areas should be burning. The fire will usually be surface level with mild to moderate movement through understory vegetation and flame lengths less than four feet (Sugihara et al., 2018).

Fire severity can be defined as the extent of the damage or effects that an area withstands from a fire (Figure 6). This is usually a reference point for vegetation, but is often applied to wildlife habitat, property damage, and loss of human life. Oak woodlands and mixed conifer forests would be considered as low fire severity, meaning little to no modification of vegetation structure following a fire, with the majority of mature plants surviving (Sugihara et al., 2018).

Ocular estimate				RdNBR
Description	Fire severity class*	Fire severity label	Percentage basal area mortality	Fire severity class
Unburned	0	Unburned	0	1
Lightly burned, no sig. overstory mortality, patchy spatial burn pattern, groups of surviving shrubs/saplings	1	Low	0–10	2
		Low	10–25	3
Lightly burned, isolated overstory mortality, most saplings/shrubs dead	2	Low-moderate	25–50	4
Moderately burned, mixed overstory mortality, understory mostly burned to ground	3	High-moderate	50–75	5
High intensity, significant proportion (75–90%) of overstory killed, dead needles remaining on trees 1 yr later	4	High	75–90	6
High intensity burn, total/near total mortality of overstory, most needles consumed in fire	5	High	>90	7

Figure 6: Assessments of fire severity including damage descriptions and severity classes. (Welch et al., 2015)

Fire type is the final attribute of magnitude, described as the flame patterns that are representative of a specific ecosystem. “Surface-passive crown fires” are most typical for oak woodlands, with a majority of the fire’s movements occurring at the surface. Torching may occur in up to a third of living trees, but most of the burning takes place amongst organic layers on the ground (Sugihara et al., 2018).

The mixed conifer forests of the North Coast bioregion display tendencies of “passive-active crown fires”, where areas see continued accumulations of surface fuels and the potential for fires to climb upwards into the tree canopies. It should be noted that given high fuel loads, appropriate weather conditions, and topographical variation, both of these ecoregions may move to “multiple fire type” in which the fire may jump from level to level with great variability.

3.2 Fire Adaptations in Bioregions

The effects of fire vary greatly from species to species. The interactions that take place between fires and a plant depend on a number of variables. These variables are much like the conditions that help define fire regimes: seasonality, fire frequency and size, fire type and severity, etc.… Therefore, plants species are not necessarily adapted to fire, but instead to a fire regime (Merrill et al., 2018). Their ability to survive in a fire-prone environment depends on the traits that allow them to persist under such circumstances. Likewise, some species may depend on that precise fire regime and those fire interactions for its survival.

These distinctions in plants are known as either fire resistances or fire persistence. Plant species who resist fire damage do so through structural strengths such as thick bark or moisture-retaining foliage. Those that persist specialize in expansive regenerative abilities once the burn has occurred. Many of these abilities are stimulated by the plants' physical or chemical reactions to fire.

An example of such persistence can be found in mixed conifer forests in Bishop pine trees. Bishop pines (Pinus muricate) are poorly protected from fire by their bark as it is relatively thin and allows heat damage to the tree's interior. Therefore, many Bishop pines will succumb to the fire damage and die, but not before releasing the seeds from their serotinous cones. Following the fire, the pines will regenerate in dense stands and continue its distribution through stages of succession, eventually replicating a mature forest with high percent cover. Strong revegetation responses in Bishop pine require a high-severity, low-frequency fire regime, needing a high mortality rate of current population to release the elevated counts of seed and prompt the dense regeneration (Merrill et al., 2018).

The California black oak is an example of a species showcasing tendencies of both fire resistance and persistence. California black oaks can survive most low intensity burns due to the moderate thickness of their basal layer bark (Skinner et al., 2018). Smaller fires will burn grasses and shrubs and likely kill young oak trees, but the mature trees can withstand the heat due to their protective bark. In higher intensity fires in which there is extensive flame damage throughout the tree, black oaks are able to refocus their energy stores to ensure its best chances for survival. Following the burns, the tree will go through robust sprouting of the root collar, bole, or crown to replenish the tree with new growth (Skinner et al., 2018).

The state of California has a long and vibrant history of fire, prompting many species to adapt to or rely upon its presence. As fire regimes are altered and vegetation patterns shift, so too must the relationships of plants with their environment. As if this ecological transference weren't challenging enough, the threat of invasive species continues to complicate matters further.

4. Fire and Invasive Species

"In a world where biological diversity is considered imperiled, the transformation of ecological interactions and ecosystem properties by invasive species poses both an immediate and a chronic threat to preservation, management, and restoration of parks, refuges, and reserves (Harty. 1986, Gordon. 1998)" (Klinger et al., 2018)

The threat of invasive species on a landscape is hardly a novel idea, but it is becoming increasingly hard to ignore. Of late, there has been greater attention given to the probable and potential impacts of the exotic species on vegetative communities, particularly regarding fire regime change (Mack and D'Antonio, 1998, Keeley et al., 2006, Zouhar et al., 2008, Lambert et al., 2010). The effects of these ecological changes take place largely through the transformations of landscapes in ways that reduce the adaptability and competitiveness of native communities (Bell et al., 2015). In creating a more suitable environment for themselves the invasive species often reduce the overall plant diversity, which in turn has lasting effects on the entire biotic community.

Not all non-native species are equally destructive and aggressive. There are some that persist for a time, thriving on specific conditions only to be replaced by something else once the appropriate environment disappears. The University of California Invasive Plant Council has documented and digitized its own inventory of California invasive plants, including a rating for how likely they are to spread and cause ecological or economical damage (Cal – IPC rating).

Mediterranean climates such as our own are particularly prone to invasive outbreaks given the multiple months of dry weather experienced each year and our continued confidence in fire exclusion. Seeing as Mediterranean climates can contain some of the highest counts of biodiversity outside of the tropics, there is much at stake in the preservation of California's many diverse ecosystems (Brooks et al., 2016).

Areas featuring disturbed or exposed soils are especially at risk to plant invasion. When fire occurs in or around disturbed areas, these spaces provide favorable conditions for nonnatives to exploit and spread. To quote Wohlgemuth et al. (2018) "Fire derived charcoal (black carbon) can greatly improve soil productivity by providing a reservoir of essential plant nutrients, improving soil water-holding capacity, detoxification of plant and microbial-inhibiting compounds, and soil warming capability". While these circumstances are ideal for the growth of most plant species, nearby invasive species are more likely to seize the opportunity due to their aggressive and persistent nature. Their advantageousness is what allows them to thrive and outcompete other species, and in essence, is what deems them invasive.

Grasslands seem to be both the leading perpetrator and most afflicted when it comes to invasive establishment in California. While the California Native Grassland Association estimates native grasslands in California have been reduced by 99%, nonnative grasslands are certainly expanding and often act as the most frequent mechanism of fire regime change (D'Antonio and Vitousek, 1992). The replacement of native perennial grasses with invasive annuals not only leads to regime alterations, but the increased encroachment of these species into forests and woodlands as well (Figure 7).

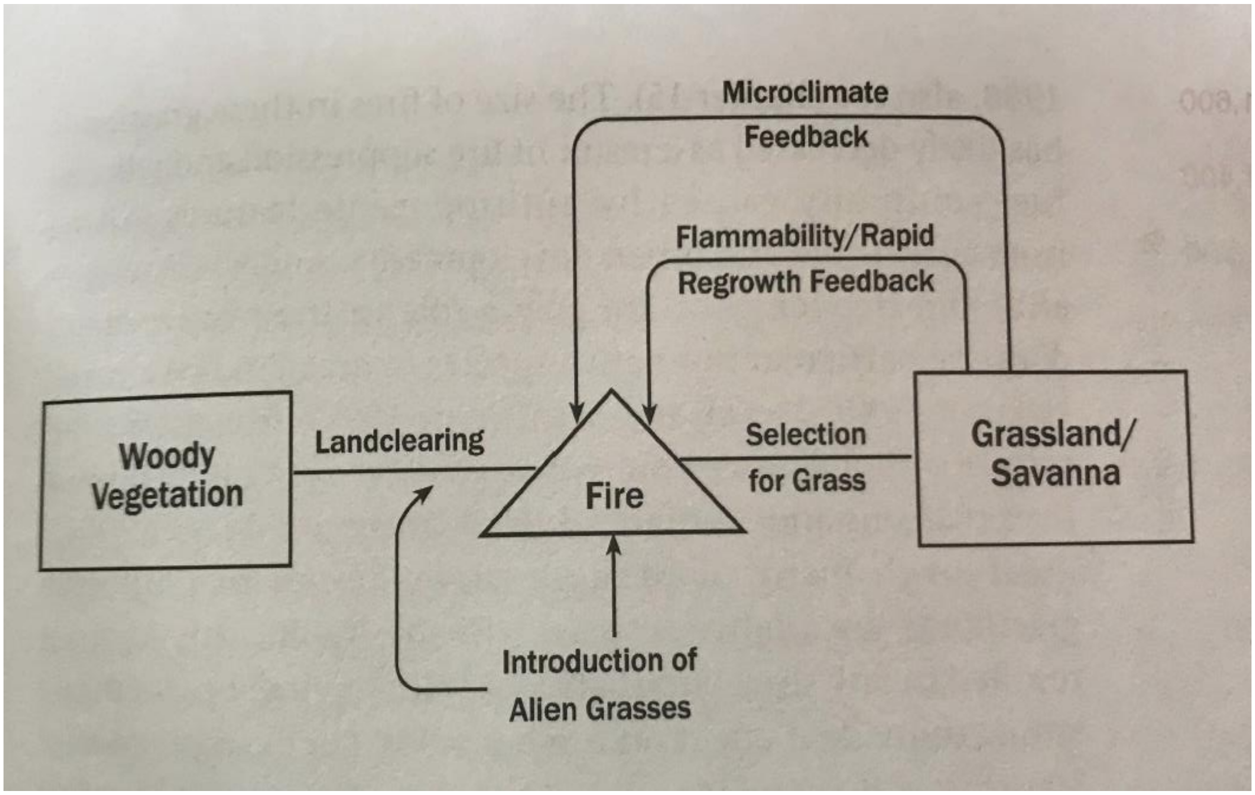


Figure 7: Visual representation of effects of grass-fire cycle. Increases in fire starts, rate of spread, and fire frequency lead to eventual decreased length of fire return intervals. The resultant scenario is the reduction of forests and shrublands and spread of nonnative grasslands (D'Antonio and Vitousek, 1992)

Fire suppression has also played a key role in the proliferation of invading grasses and resultant regime changes. The fine fuels deposited by the annual grasses have a higher ignition rate than the surrounding woody vegetation, which increases the probability of fire starts and fire spread rates. This results in the reduction of time in fire return intervals and may lead to the eventual transformation from woodlands and forests to nonnative-dominated grasslands (Klinger et al., 2018). While the conversion from woodlands to grasslands may be occurring at a gradual rate, the alterations of fire regimes have brought about dramatic vegetation shifts currently present in both oak woodlands and mixed conifer forests.

5. Findings on Forests, Fires, and Invasives

For the purposes of this paper I have divided the findings section into three categories: Invasive Influences, Conflicted Conifers, and Encroached Oaks. While each of these sections offer findings distinct from one another, there remains an amount of continuity present. The effects of fire suppression and subsequent fire regime changes are apparent in each segment, with noticeable differentiation in the ecosystem dynamics and responses to such changes. The diagram listed below presents a visual summary of the impacts associated with my findings, numbered in the same order as the categories are represented in this paper.

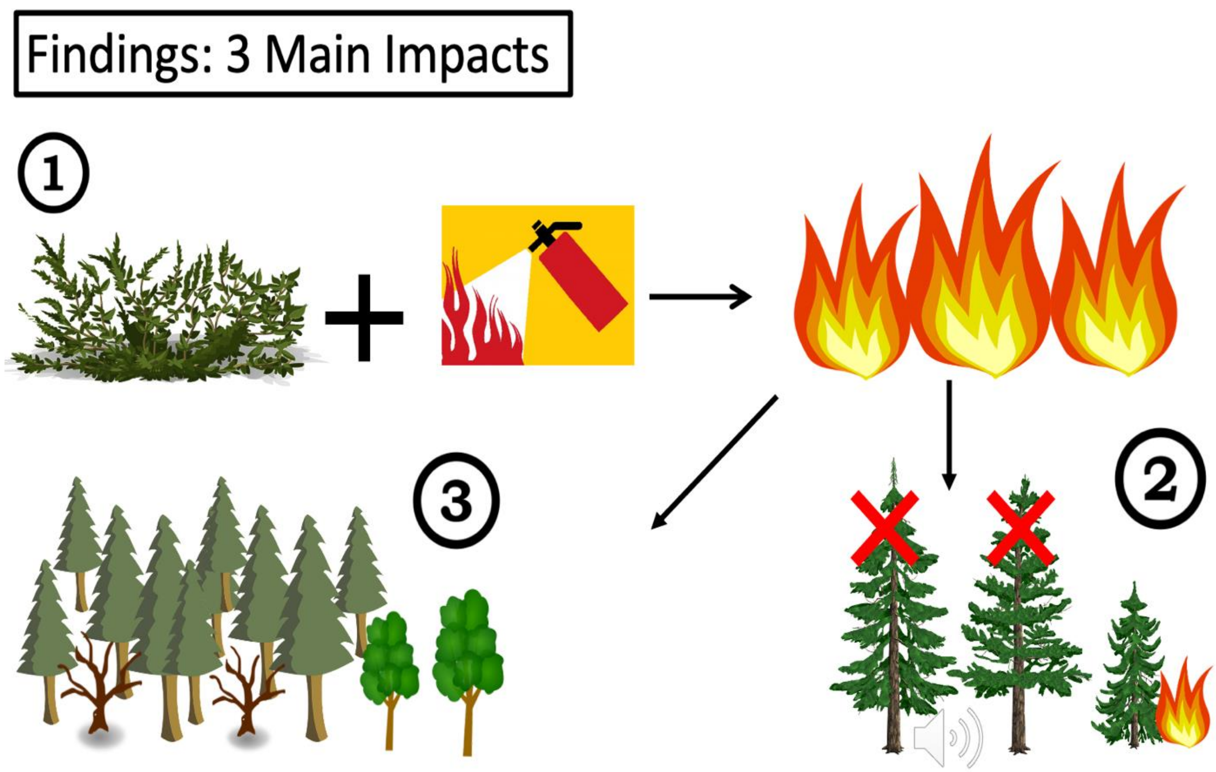


Figure 8: Diagram showing 3 primary impacts discussed in Findings (Author)

5.1 Invasive Influences

"Human activities have drastically modified native habitats through direct disturbance and indirect effects such as, exotic species invasion and altered fire regimes. As vectors of exotic plant dispersal, humans have aided in the invasion of disturbed and intact wild lands. Once established, exotic plants may significantly alter plant community composition as well as soil characteristics" (Dickens and Allen, 2014).

5.1.1 Mixed Conifer Forests

Coniferous forests have encountered drastic ecosystem alterations due to fire regime change, leaving long-term impacts on forests throughout the state. While these effects will be featured at length in the "Conflicted Conifers" section of this paper, the direct role of invasive species on mixed conifer forests is much less noticeable. In Klinger et al. (2006) there were notable findings regarding the lack of invasive species in monitored plots in Yosemite National Park. There was a total of 598 plots monitored throughout the park, distributed between Natural Resources Inventory program (NRI – 362 plots) and The Nature Conservancy/ USGS (TNC – 236 plots). Of those 598 plots only 46 invasive species were discovered, with a total invasive representation of 8.1%. This total takes into consideration broadleaf woodlands, chaparral, and grasslands and meadows as well, but (Figure 9) shows the low frequency in which invasives persist in the coniferous portions of the park; though it should be noted that the Lower Montane Coniferous forest (LMCF) featured noticeably higher counts (Figure 10).

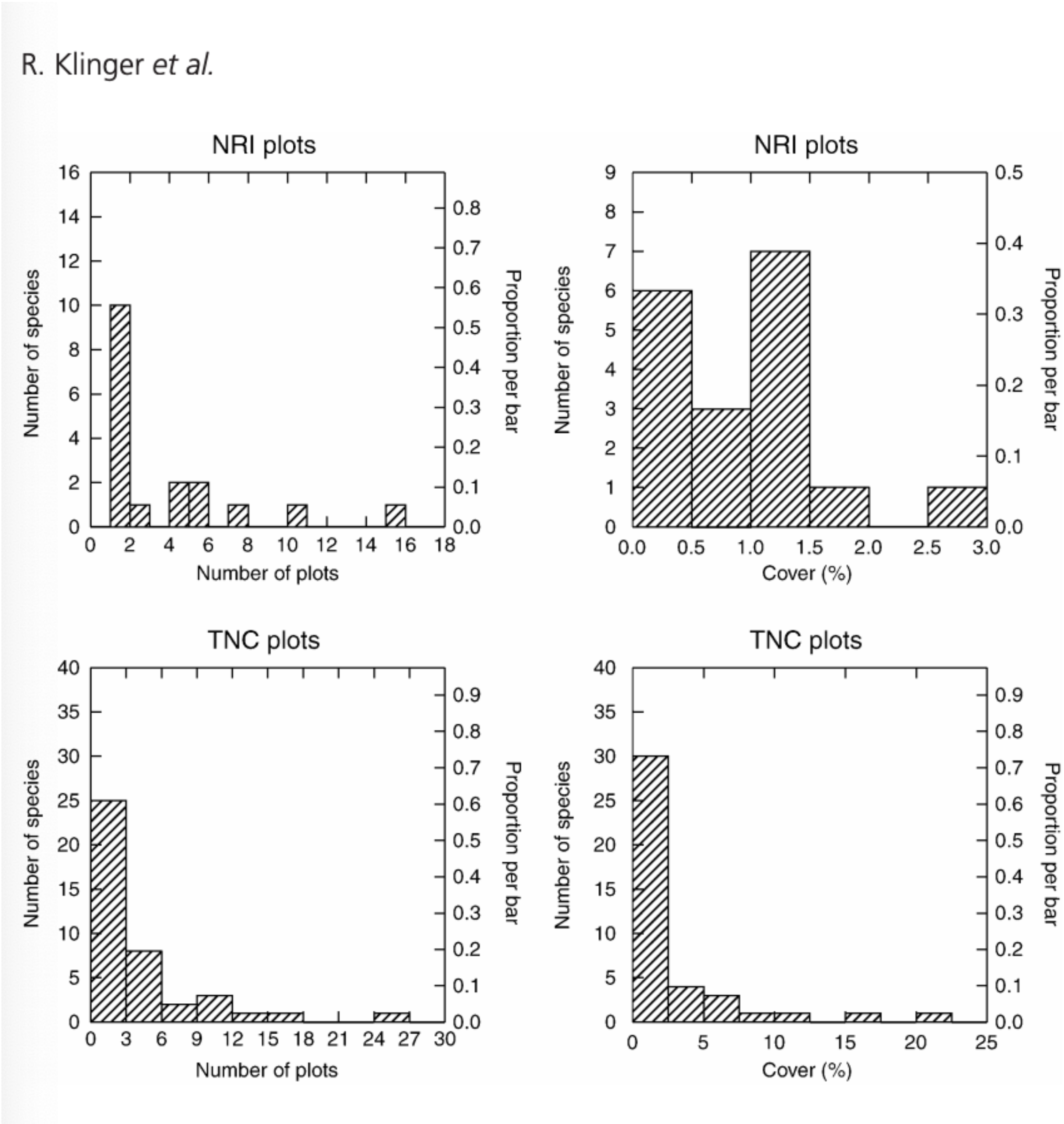


Figure 9: Recorded distribution and abundance counts of invasive species across both NRI and TNC plots. (Klinger et al, 2006)

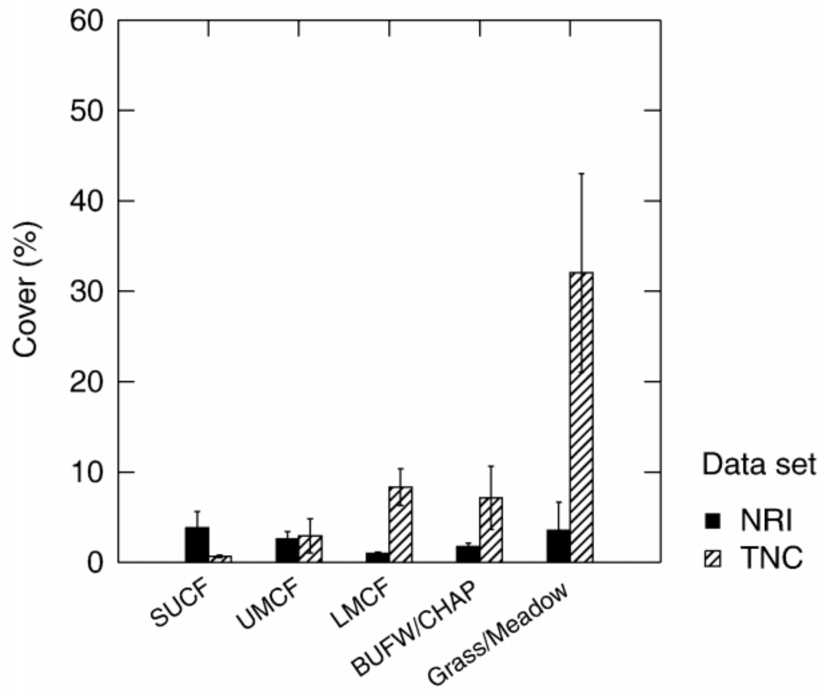


Figure 10: Representation of the mean coverage of invasive species in Yosemite National Park. Vegetation formations of focus are UMCF (Upper Montane Conifer forest) and LMCF (Lower Montane Conifer forest). (Klinger et al, 2006)

Their study also concluded that with in increasing elevation there would be decreasing totals of invasive species, regardless of whether the area had encountered fire or not. They also determined that due to the low rates of invasion it was unlikely that any fire regime alterations or drastic changes to the vegetative composition would occur, especially in the upper elevations.

Similar sentiments were found in Keeley et al. (2011), noting other factors that could influence the lack of invasive pressure as you move up in elevation. The presence of a shorter growing season, the lack of consistent light on the forest floor, and distinctive disturbance regimes were some of the ideas voiced in the publication. It was also surmised that the higher elevations offer more difficult climates for invasive species to inhabit, leading to less exotic species propagation and establishment in higher climes.

Keeley continues to suggest that some of the current problems with invasive species in forests stem from prior management practices. Fire suppression, logging and grazing practices have contributed to the shift in fire regimes, replacing low to moderate–severity burns with high-severity fires that create greater opportunities for invasive species to exploit a landscape.

This scenario is well represented in the Franklin et al. (2006) within the mixed conifer forests of Cuyamaca State Park in San Diego County. After a high-intensity fire in 2003, much of the park's existing conifer forests were destroyed. The regrowth of the conifers has been slow and sporadic, as dense populations of shrub have taken advantage of the access to sun and disturbed soil. The existence of large swaths of native and non-native herbs have also obstructed the recovery of these areas, and high counts of the very invasive cheatgrass (Bromus tectorum) were found moving up through meadow sections into formerly forested hillsides.

The lack of sunlight and moisture in full-canopied conifer forests deny invasive species the ability to settle and propagate, but canopy gaps can allow opportunities for invasive establishment. The reduction of canopy presence due to high-severity fires can lead to the proliferation of invasive populations, even in large conifer forests, as evidenced by Franklin et al. (2006). Keeley (2001) also connected this notion, finding invasive counts to be higher in conifer forests with canopy breaks, though he noted that this expectation of increased invasive counts occurs on a shortened timeline. This is because once the tree canopy does begin to fill-in, the territory for the exotic populations shrinks as competition increases for the dwindling sunlight. As the surface-level sunlight is reduced, typically so too are the invasive populations. However; in cases such as Franklin et al. (2006), the absence of adequate conifer recovery may allow shrub species to effectively crowd out the miniscule counts of conifer seedlings. With the reduction of conifer recovery, the invasive populations may become established as the area transforms into a shrub-dominated landscape.

From Klinger et al. (2018) "Over the last 10-15 years, there has been increasing evidence indicating that the level of invasive plant dominance in burned conifer stands depends on fire frequency and severity (Keeley 2001, Keeley et al. 2003, Franklin et al. 2006, Franklin 2010, Kaczynski et al. 2011)." It appears that in the context of mixed conifer forests invasive species remain as more of a pest than a legitimate risk to the health of the ecosystem. The shift in fire regimes remains the larger threat, an issue that will be explored in Conflicted Conifers.

5.1.2 Oak Woodlands

Oak woodlands are a defining characteristic of the Californian landscape, but the spread of invasive species and the disruption of historic fire regimes have diminished the prosperity of these prized ecological zones. Much like mixed conifer forests, oak woodlands are not immediately threatened by an infestation of exotic species. Most oak woodland stands will have unharmed overstory, but the understory can often become a disturbed area.

Due to the open nature of the oak woodlands, there is greater opportunity for exotic species to flourish. French broom (Genista monspessulana) can be particularly problematic for oak stands. Not only do these plants gather in dense stands, they can grow to be quite tall, potentially acting as a ladder fuel and allowing surface fires access to the overstory. The same can be said about vines and climbing plants such as Himalayan blackberry (Rubus armeniacus) and Cape Ivy (Delairea odorata) which can reach the upper portions of the canopy and carry flames up along with it.

Oak woodlands can encounter higher densities of invasive establishments due to their lower elevations and proximity to meadows and grasslands. Since California’s grasslands feature the most established populations of invasive species there is a higher likelihood that the oak woodlands would also be affected. It is estimated that in some foothill woodlands as much as 95% of the herbaceous vegetative mass is comprised of non-natives (Gerlach et al., 1998).

“Grasslands or understories dominated by invasive herbaceous plants contain high fuel loads from annual and perennial grasses, such as Harding grass (Phalaris aquatica), medusahead (Elymus caput-medusae), wild oats and bromes (Avena spp. and Bromus spp.), ryegrass (Festuca perennis), and invasive thistles (Carduus spp., Cirsium spp., Silybum marianum). Since invasive herbaceous plants act as flashy fuels, they facilitate the spread of fire into unburned areas and in grassy understories below woodlands and shrublands. They also can increase the frequency of fire and length of the fire season in the future" (CNPS, 2019).

California Native Plants Society also mentions the dual roles some of these invasive plant species can have to manipulate the landscape for their own benefit. Plants such as cheat grass (Bromus tectorum) and red brome (Bromus madritensis subsp. rubens) are both able to act as facilitators of fire and advantageous colonizers once burns have occurred. Not only will they quickly establish themselves after a fire, but they have the ability to change the ecosystem's fire regime, thus doubling the danger they pose to existing woodland populations. Cheat grass has been found to have affected the most area in the intermountain regions of the American West, noting the potential for populations to change fire regimes since the mid-1900s (Lambert et al., 2010).

Star thistle (Centura solstitalis) is another species highlighted by CNPS that is particularly prone to taking over disturbed areas, returning after a burn in much greater numbers and crowding out former-site inhabitants. The rapid growth rate of star thistle can lead to substantial changes in landscape composition for both grasslands and woodlands alike and has the potential to alter fire regimes (DiTomaso et al., 2006).

Klinger et al. (2006) found that in Yosemite National Park oak woodlands featured higher totals of invasive species than coniferous forests (Figure 10). This was thought to be in line with their idea that lower elevations are more prone to invasive populations due to having more hospitable environments, though it was mentioned that it is likely that other physical gradients factor into the relationship.

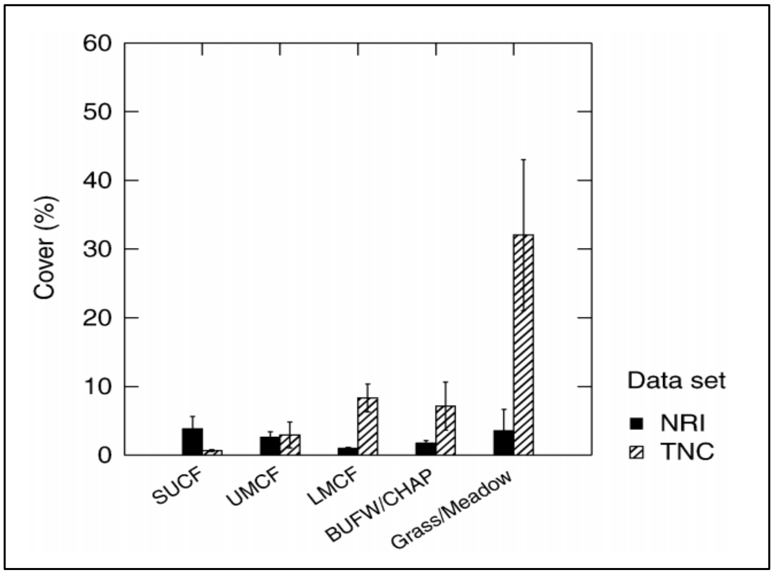


Figure 10: Representation of the mean coverage of invasive species in Yosemite National Park. Vegetation formations of focus are BUFW (Broadleaf Upland Forest and Woodland) and Grass/Meadow (Klinger et al, 2006)

5.1.3 Does Fire Regime Change Lead to Greater Invasive Populations?

This leads to the question of whether invasive populations increase as historic fire regimes are disrupted. The California Invasive Plant Council have an inventory of 104 plant species that are capable of changing fire dynamics or are likely to see population increases following a fire. Seeing as the ecological processes that formed these vegetative communities no longer function as they once did may allow for exotic species to take advantage of the changed conditions. Huenneke (1997) subscribed to this concept, that the farther an ecosystem gets from its historic regime, the higher the likelihood that the ecosystem can succumb to exotic invasions. This may apply to any type of change within the fire regime, but the areas most well regarded are fire frequency and severity. This can include cases in which fire exclusion, or possibly increased fire frequency have led to increased stress on native populations that were originally adapted to different relationships with fire.

From Mack and D'Antonio (1998) "Invasion can result in a positive-feedback between disturbance and the abundance of non-native species, such as the positive-feedback observed between some introduced grasses and fire (Vitousek, 1986)". Mack and D'Antonio (1998) continue by suggesting that invasive species can function as either the initiator or enhancer of fire events or can act as the disturbance themselves by interrupting ecological functionality or by quickly displacing large portions of the native community.

In regard to the situation with oak woodlands and mixed conifer forests Zoubar et al. (2008) states “Exclusion of fire from open-canopy forests, on the other hand, has led to increased surface and ladder fuels and subsequent increases in fire severity in some areas, when the forests eventually burn. Native plant communities are likely to be adversely impacted by fire under these fuel conditions, so nonnative species may be favored in the postfire environment.” Zouhar et al (2008) continues with this thought, suggesting that this may also apply to ecosystems that have seen increased fire frequency through either increases in human-induced ignitions or invasive species-induced changes in fuel structure. This is apparent in the inability for many conifer forests to recover after high-severity fires. Though invasive species are not the direct connection in this example, the actions of forbs and shrubs resemble those of exotics, quickly establishing and outcompeting the limited conifer starts.

Though the blanket question of “whether an ecosystem with a changed fire regime will see more invasive impacts” is hardly answerable at face-value, it does appear to be applicable within the contents of this paper. Mixed conifer forests have seen similar conditions presented in the form of devastating stand losses from high-severity fires. The fire regime shift from frequent low to moderate severity fires to infrequent, but high severity fires can have drastic effects on the conifer populations. With entire stands reduced to nothing, there is ample opportunity for invasive species to become established. The access to sunlight, nutrients, bare soil, and low competition for resources can allow invaders to quickly dominate the landscape. In accordance with Huenneke’s proposal, the scenario offers invasive species a stronger chance of settling as many native populations may be slow to adjust to the new conditions.

As for oak woodlands, the proximity to grasslands, the lower elevation expectancy, and the openness of the canopy all encourage higher probability of invasive counts and resultant regime impacts. Annual grasses have the strongest effects on fire regimes, creating heavy concentrations of fuels and large continuous swaths of flammable material (Lambert et al., 2010). Given the threats of invading grasses as well as the encroachment of conifers into oak woodlands it appears this ecozone is at risk. In Californian shrublands when fire frequency is increased it creates shorter fire intervals can lead to increased exotic invasions (Keeley, 2006) so it may be a similar situation with the influx of flammable annual grasses.

Based on these accounts I would suggest that it is likely both oak woodlands and mixed conifer forests see increased rates of invasive impacts when they encounter alterations to their historic fire regimes. With the expectation of climate change bringing potential long-term trends of increased fire weather across the state in our fire-prone Fall months (Goss et al., 2020), ongoing management of these areas will be vital to maintaining ecosystem health and community structure.

5.2 Conflicted Conifers

Fire has held many roles in the make-up and maintenance of California forests for thousands of years. Human impacts over the last century have altered the relationship between fires and forests, leaving variable, but virulent effects on the landscape. Perhaps no other forest ecosystem is seeing such drastic changes as that of mixed conifer forests. From significant shifts in speciation and the buildup of high fuel loads, to sweeping regime changes and near-complete eradication of conifer stands, the outcomes of these alterations are dramatic and disconcerting.

The most urgent findings came from the study Welch et al. (2016), an expansive research effort covering the 14 fires across 10 Californian National Forests. 1490 surveys plots were utilized across a range of elevations and forest types in northern and central North American Mediterranean climate zone (NAMCZ), with 13 of the 14 fires occurring in Northern California.

These forests would historically see frequent low to moderate-severity fires with a return interval of 11-16 years (Figure 11). This regime allows the forests to reduce the fuel loads, maintain the heterogeneity of the landscape, and restore its structure after each burn. While some pine forests benefit from high-severity fires, mixed conifer forests have not adapted to such events (Safford et al., 2012). The lack of high-severity fires in their historic regime means that the species are ill-equipped to deal with such intense burns and therefore, experience negative effects to plant regeneration and diversity, oftentimes resulting in vegetative shifts to shrublands (Stevens et al., 2015).

Forest type	Mean FRI (yr)	Mean min. FRI (yr)	Mean max. FRI (yr)	Dominant tree species
Mixed evergreen	29	15	80	*Quercus* spp.
				Arbutus menziesii
				Notholithocarpus densiflorus
				Pseudotsuga menziesii
Dry mixed conifer	11	5	50	*Pinus ponderosa*
				P. lambertiana
				Calocedrus decurrens
				Abies concolor
				Quercus kelloggii
Moist mixed conifer	16	5	80	*A. concolor*
				P. menziesii
				C. decurrens
				Pinus lambertiana
				P. ponderosa
Yellow pine	11	5	40	*P. ponderosa*
				P. jeffreyi
				P. lambertiana
				Q. kelloggii
Fir	40	15	130	*A. concolor*
				Abies magnifica

Figure 11: The historic fire regimes (pre-Euro American settlement) of related forest types with emphasis on Fire Return Interval (FRI). Based upon CALVEG (Classification and Assessment with Landsat of Visible Ecological Groupings) (USDA, 2013) classification. (Welch et al., 2016)

Franklin et al. (2006) contributed similar findings regarding the recovery of conifer populations following a devastating wildfire in San Diego county in 2003. The Cedar fire was a high-severity crown fire that resulted in high counts of mortality among trees, especially conifers. While not all trees were killed immediately in the blaze, many succumbed to the initial damages in the weeks to follow. In the first two growing seasons following the Cedar fire (May-June 2004, 2005), plots in Cuyamaca Rancho State Park (CRSP) were utilized to identify and accumulate data on remaining conifer and oak populations. In 2004, the West Mesa plots accounted for 2,155 trees: 1,162 (54%) were conifers and 993 (46%) were oaks. The conifers experienced a 95%

mortality rate, while oaks saw just 17%. In 2005, there was increased conifer mortality at 98% and decreased oak mortality at 12% (Figure 12).

Resprouting and recovery were fairly consistent among oak populations, but low regenerative rates of pines and the high number of mature conifers killed by the fire is concerning. Coulter pines (Pinus coulteri) were the one of the most prominent conifer species observed in the park, but very few pine seedlings were found in the first year, with even less the following year. The lack of new pine potentially shifting the forest composition.

Variable	Mean (S.D.)		Paired t-test, p-value
	2004	2005	
Conifer mortality	95.19 (13.38)	98.38 (3.98)	0.068
Oak mortality	17.13 (16.51)	12.46 (14.85)	<0.001
Shrub-seedling count	0.525 (0.365)	0.375 (0.215)	<0.001
Shrub-seedling cover	1.65 (1.91)	11.24 (10.90)	<0.001
Shrub-sprout cover	1.38 (2.08)	5.54 (7.26)	<0.001
Native annual cover	17.2 (13.98)	32.92 (14.95)	<0.001
Native perennial cover	6.43 (5.88)	9.68 (8.76)	0.008
Exotic annual cover	3.02 (5.28)	15.02 (13.10)	<0.001

Mortality and cover are percentages. Seedling count is average number per m^2.

Figure 12: Abundance changes of plant groups after Cedar Fire in San Diego (Franklin et al., 2006)

There is also the issue of the ecological shift in conifer forests from shade-intolerant, but fire-resistant species such as Ponderosa pine (Pinus ponderosa) and Jeffrey pine (Pinus jeffreyi) to shade tolerant, fire-sensitive species such as Douglas fir (Pseudotsuga menziesii) and incense cedar (Calocedrus decurrens) (Figure 13). This shift is a result of fire suppression, the reduction of smaller, more frequent fires and the subsequent build-up of fuels to bring about higher-intensity fires. The thick bark of young Ponderosa and Jeffrey pine shield them from the potential damages of low to moderate-severity fires, enabling the survival of new stands following a blaze. The two species also have the ability to self-prune the lower limbs of their trees, allowing them to distance themselves from surface fires and reduce the risk of ladder fuels guiding flames into the crowns (Safford and Stevens, 2016).

Group	Species	Scientific name	Symbol	Elevation (m)	Seed weight (g)	Ecological tolerance		
						Shade	Drought	Fire
Firs	White fir	*Abies concolor*	ABCO	300–2100	0.015–0.055	High	Low	Low
	Red fir	*Abies magnifica*	ABMA	1700–2300	0.015–0.07	High	Low	Low
Incense cedar	Incense cedar	*Calocedrus decurrens*	CADE	600–2100	0.015–0.07	High	Low	Low
Douglas-fir	Douglas-fir	*Pseudotsuga menziesii*	PSME	300–2100	0.01–0.02	Intermediate	Intermediate	Intermediate
Pines	Ponderosa pine	*Pinus ponderosa*	PIPO	300–1800	0.02–0.07	Low	High	High
	Jeffrey pine	*Pinus jeffreyi*	PIJE	1500–2400	0.08–0.2	Low	High	High
	Sugar pine	*Pinus lambertiana*	PILA	1000–2000	0.15–0.3	Low	High	Intermediate

Figure 13: Common conifer species located in study sites. Habitat specifications and ecological tolerance of each focus species, grouped by similarity to shade, drought, and fire. (Welch et al., 2016)

The adaptations of this forest type contrast that of the conifer species becoming increasingly dominant, thus reinforcing the regime change and hastening the demise of the historic conifer stands. Across all observed burns in the Welch et al. (2016), 43% featured no regeneration of conifer populations. All forest types experienced plot returns of zero seedlings – yellow pine: 61%, dry mixed conifer: 41%, moist mixed conifer: 41%, mixed evergreen 38%, and fir: 38%. The interior of severely burned areas fared the worst, seeing little to no regeneration in any of the plots as these portions were located farther from potential seed trees and contained a greater presence of shrub species. The seed banks of most conifers are short-lived when burnt prior to maturity and unlikely to account for strong regenerative counts.

10 out of the 14 fires in the Welch study found the densities of the conifer seedlings too low for Forest Service standards. The regenerating portions were dominated by conifers such as Douglas fir (Pseudotsuga menziesii), incense cedar (Calocedrus decurrens), and mixed firs (Abies ssp.) – all species that can be shade tolerant, but typically insensitive to fire. The lowest regeneration rates came from the areas that saw the highest severity of fire. This was experienced across all areas of study, with the median density of regeneration a zero in high-severity plots (Figure 14). The highest conifer regenerative returns were observed in areas of low to moderate severities.

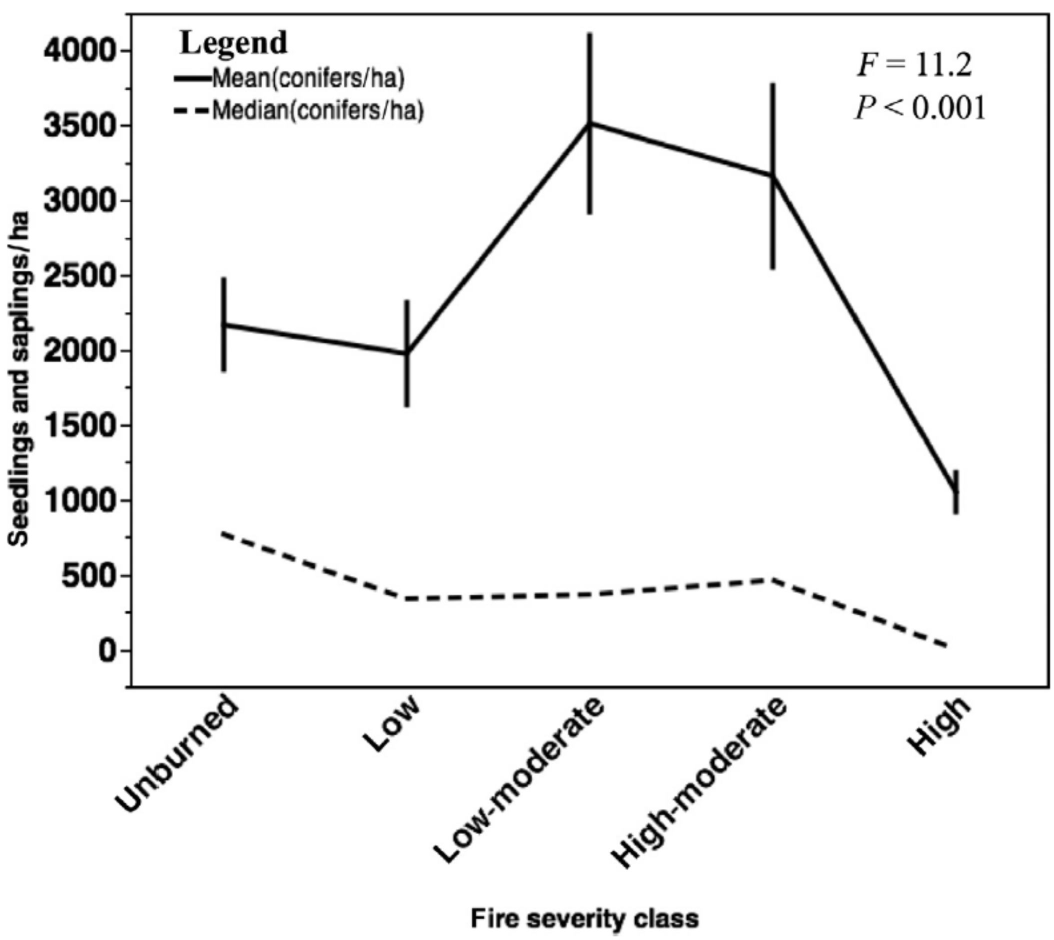


Figure 14: The progression of mean and median conifer seedling densities as determined by fire severity. (Welch et al., 2016, Safford et al. 2012)

It was found that in eight of the fourteen fires, shade-tolerant species of conifers outnumbered original pine species, with noticeable increases in incense cedar throughout. Incense cedar is able to mature in full shade and is much less susceptible to insect damage and disease than most conifers, resulting in increasing populations throughout much of the lower-Sierra (Smith et al., 2005)

The opposite case is true for Yellow pine (Pinus ponderosa), the trees that Barbour and Minnich (1999) call "the biological thread that holds the forest together". Not only are they much more fire-resistant than the incoming stands of shade-tolerant conifers, they are more drought-tolerant as well. Aside from their resiliency, they are very valuable as a form of food source and habitat to wildlife (Safford and Stevens, 2016). The current situation presented by fire suppression and the subsequent shift to shade-tolerant conifer species has left the forest floor with deep layers of litter and darker forest floors, unfavorable conditions for the recruitment of yellow pine.

There was also a strong relationship between severity and litter cover, shrub and herb cover, live tree canopy cover, and amount of bare ground, with uncovered soil increasing from 5% in unburned areas to 13% in high severity plots. The litter cover percentage dropped sharply from 80% in unburned areas to below 50% litter representation in severely burned areas. While shrub coverage increased with fire severity, herb coverage appeared not to be determined by severity, though it increased from 8% in unburned plots to 20% in severely burned plots.

That the areas seeing the least amount of regrowth featured a drier forest type suffering from a high-severity fire is quite worrisome for the future livelihoods of these forests. As our climate continues to change, less precipitation and larger fires are expected for much of California, threatening the sustainability of conifer forest populations in similar regions (Lenihan et al., 2008).

5.3 Encroached Oaks

Reliance on frequent fires has defined and helped maintain California's oak woodlands, providing resiliency to its native inhabitants and the great diversity of species that characterize the ecosystem. The mixture of understory vegetation made up the fuel load that prompted the low-intensity fires to maintain the open canopy and reduce populations of fire-intolerant species. As fire exclusion increased, so did the amount of fire-sensitive species, whose vegetation coverage and density began to counter those of native species. Our insistence on fire exclusion has led to this shift in vegetation, disconnecting the historic fire patterns and disrupting the ecological processes that revolved around them.

"This shift in fire regimes has resulted in the ingrowth of fire-sensitive species, resulting in denser vegetation and increased fuel loads in many western forests" (Sugihara et al., 2018). On top of the decreased counts of landscape diversity, the shifts in structure and forest composition bring about greater risks of high-severity fires. California black oak in particular has seen drastic declines in population since the initiation of fire suppression.

Despite the numerous adaptations that oaks hold in fire-prone environments, they can become very vulnerable to the intrusion of conifers once the element of fire is removed from the landscape. Without the typical fire frequency there is no longer the existence of the negative feedback loop that would prevent the buildup of fuel loads and support the open canopy needed to provide surface fuels for low-severity fires. Instead the woodlands become forest-like, featuring closed-canopies, dense growth of fire-intolerant species, and the amassment of heavy fuel loads (Figure 15).

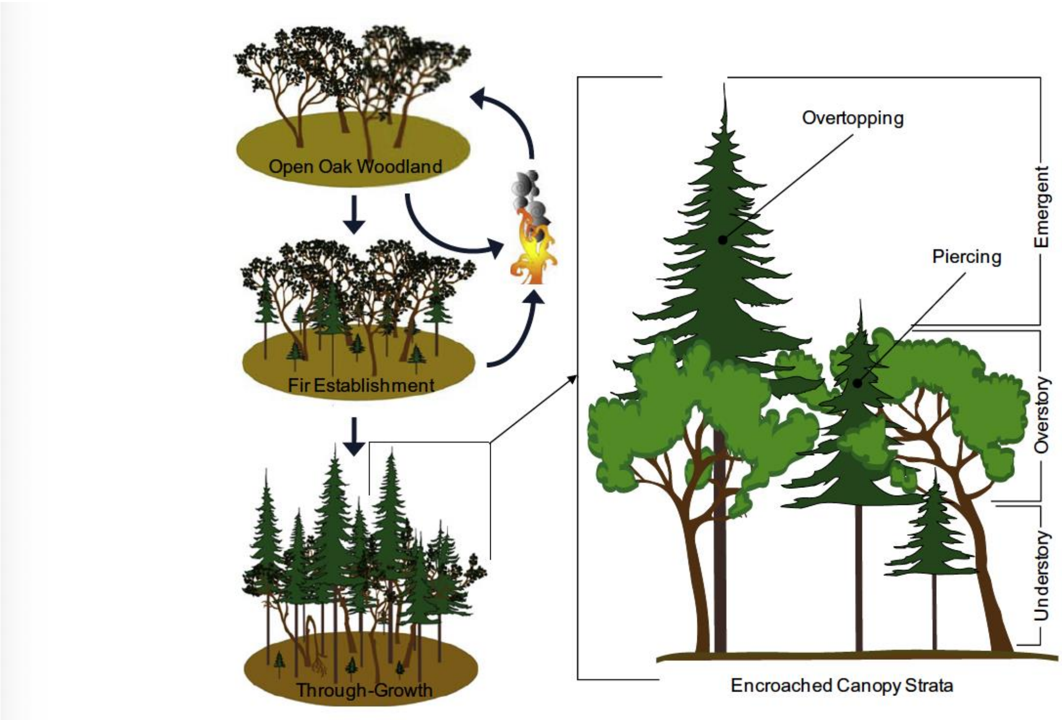


Figure 15: Representation of how the lack of historic fire regime enhances conifer encroachment. (Cocking et al. 2012)

The encroachment of conifers has occurred in numerous oak ecosystems including Oregon white Oak (Quercus garryana), coast live oak (Quercus agrifolia), and California black oak (Quercus kelloggii). Douglas fir (Psuedotsuga menziesii), white fir (Abies concolor), and incense-cedar (Calocedrus decurrens) are some of the most common conifers encroaching on oak woodlands. These conifer species are typically fast growing, shade-tolerant, and fairly intolerant to fire, particularly when young.

The effects of conifer encroachment can be noticeable relatively quickly with initial understory dominance occurring within 5-10 years and reductions in oak health seen in 20 years (Figure 16).

Region	Encroaching species[a]	Understory cessation (years)	Oak crown recession[b] begins (years)	Oak mortality begins[c] (years)	Oaks replaced[d] (years)
North Coast Ranges	PSME	5-10	20-30	30-40	60-100
Western Klamath	PSME	5-10	20-30	40-50	80-100
Central Klamath /Trinity	PSME, CADE, ABCO	10-20	30-40	60-80	100-150
Southern Cascades /northern Sierra	ABCO, PSME	10-20	30-40	60-80	100-150
Eastern Klamath /Shasta Basin[e]	JUOC	20-30	not observed[f]	≥20	not observed[f]
Northern CA serpentine[g]	CADE, PIJE, PSME	10-20	30-50	60-80	≥100

[a] listed by commonality/importance. PSME = *Pseudotsuga menziesii*, CADE = *Calocedrus decurrens*, ABCO = *Abies concolor*, JUOC = *Juniperus occidentalis*, PIJE = *Pinus jeffreyi*.
[b] Refers to the dieback of oak crowns during the piercing stage.
[c] Oak mortality begins during the overtopping stage and peaks as stands reach the decadent stage.
[d] Refers to timeline estimates for 90 percent or greater mortality of pre-encroachment oaks within a stand.
[e] Earlier oak mortality in the Eastern Klamath and Shasta Basin is based on empirical observations at several Oregon white oak sites and might be accounted for by more severe competition for water in this arid region.
[f] Complete replacement of oaks and dieback of oak crowns was not observed with western juniper encroachment; development of these stages may be limited by lower height potential and density of western juniper.

Figure 16: The time expectancy for different stages of conifer encroachment to occur. (Cocking et al. 2015)

Cocking et al. (2015) lists four stages to conifer encroachment: establishment, piercing, overtopping, and decadent, represented in Figure 17. In the establishment phase the incoming conifers face competition from the herbaceous understory and shrub species, but the conifer’s quick development and upright structure allow them to access above the shrub stage. In time they will reach the piercing stage, in which the conifers surpass the oak canopy and are able to outcompete the lengthy, but lower-lying oaks for sunlight. In many cases the piercing stage is occurring with many conifers around the same time, an almost united movement to minimize oak overstory and fill in the gaps that typify oak woodlands (Cocking et al., 2012). The overtopped phase sees the oaks suffer from the lack of sunshine, stunting their growth and reducing the overall health of the tree. The eventual mortality of the subdued oaks marks the decadent stage, the final stage of encroachment as the conifers complete the restructuring from woodland to forest and thus initiate the shift in fire regime.

Figure 17: The four stages of conifer encroachment (Cocking et al. 2015)

The flammability of the leaf litter is a key component in the alteration of the ecosystem's fire regime. Oak woodlands typically produce fuels that are conducive to frequent burns, primarily made up of grasses, forbs, and the highly flammable oak leaf litter. Under a historic fire regime these fuels would contribute to low-intensity burns every 5-10 years, reducing conifer establishment and preserving the open-nature of the woodland ecosystem. With the conifer encroachment reducing the influences of oaks, the fuel load composition changes to conifer needles and timber litter, decreasing flammability and promoting further conifer growth and establishment.

Yet with the occurrence of a single high-severity wildfire, oaks can reestablish dominance in an area previously overrun by conifers. Nemens conducted a study evaluating the persistence of California black oaks following two fires within the same location. The two fires took place twelve years apart, Storrie fire in 2000 and the Chips fire in 2012 in the southernmost portion of the Cascade Range in Lassen National Forest. The Storrie fire burned approximately 23,000 ha while the Chips fire burned approximately 30,000 ha, with approximately 9,900 ha of overlapping area burned between the two (Nemens et al., 2018). While the Southern Cascades are not part of the North Coast bioregion, the mixed conifer forest within the area of study share many species with the North Coast bioregion, namely the ponderosa pine (Pinus ponderosa), sugar pine (Pinus lambertiana), and Douglas fir (Psuedotsuga menziesii).

Nemens study found that after the second wildfire (Chips fire), the forest composition moved back towards oak dominance, seeing high counts of conifer burn mortalities and high counts of oak resprouts (Figure 18). Ninety seven percent of oaks that resprouted after the Storrie fire also resprouted during the Chips fire. Following the second fire, the oak resprouts were found to be more plentiful, yet smaller in size, showcasing the oaks ability to self-thin over time (Nemens et al., 2018).

This study confirms much of what was suggested in Cocking et al. (2011, 2014, 2015) about the importance of fire continuation after the initial severe fire burns through. The second wildfire (Chips) reinforced the trajectory of oak dominance through the killing of the conifer saplings and continued resprouting of the oaks. This finding supports the concept suggested in Cocking et al. (2014) regarding the potential for a high-severity fire to enable oak populations to recover and become the dominant canopy species. The competitive advantage that resprouting holds for oaks is relatively momentary, however, as the absence of repeat fires will allow conifers to catch up and surpass the mature oaks, replicating the scenario we began with. Therefore, in order for oak dominance to remain, fire regimes with low severity fires at frequent intervals need to be maintained (Nemens et al., 2018).

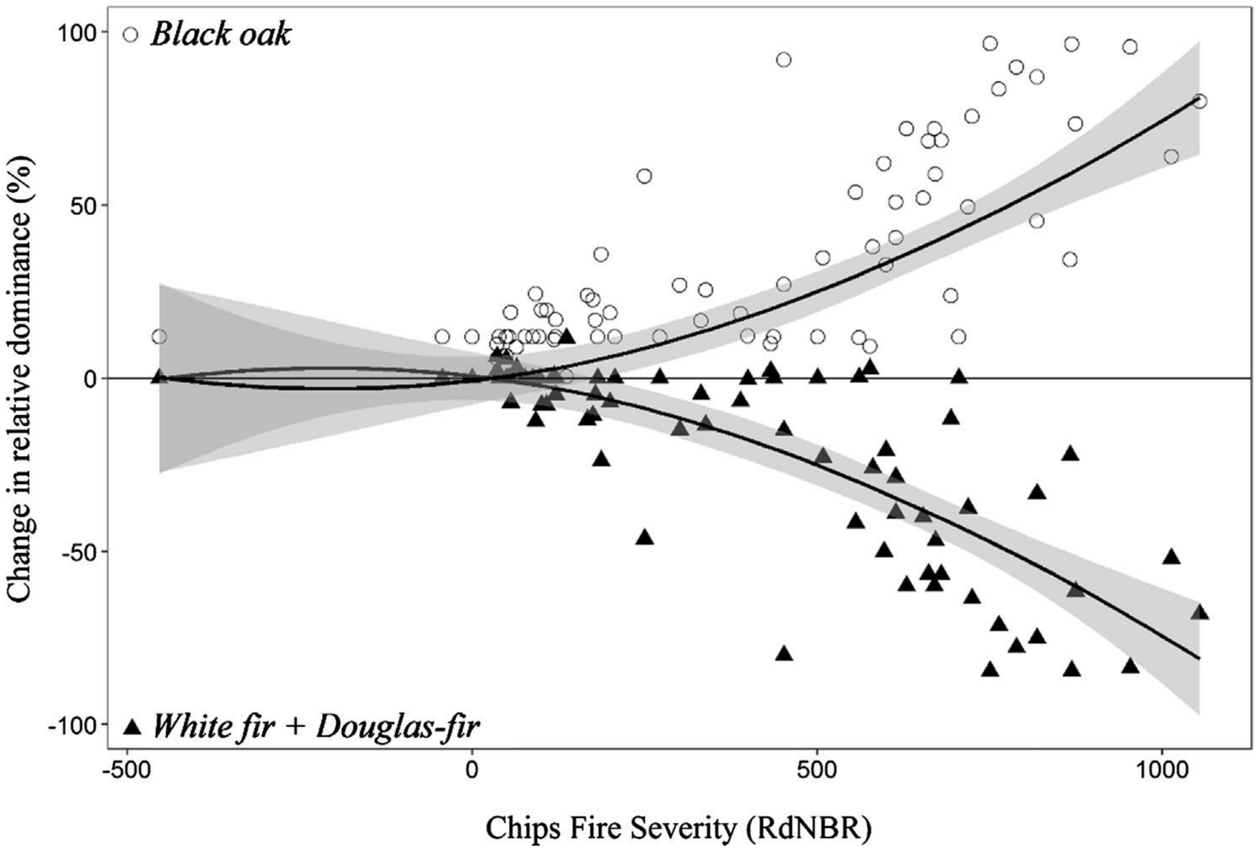


Figure 18: Representation of the change in species dominance following the Chips Fire. Increase in black oak following the second fire represented by upward swing of circles, while the diminished conifer populations are shown in the downward trajectory of the triangles. (Nemens et al., 2018)

The findings of the study offered support to numerous publications regarding the adaptability of oaks and fire. There is sufficient backing of the resiliency of oaks when facing multiple fires; however, the importance of interval dependency in regard to regeneration is still inconclusive. "In some species of oaks, shorter-interval fires have been shown to diminish regeneration (Delitti et al., 2005, Hutchinson et al., 2005), while others have proved resilient over multiple burns (Barton, 2002, Coop et al., 2016). Predicted regional increases in fire frequency will likely provide further opportunity to study this species' capacity for repeated regeneration over shorter fire return intervals" (Nemens et al., 2018).

Despite the dependency on fire and the ability to rapidly resprout following fire, California black oaks are still sensitive to fire in their youth. It has been suggested that black oaks require 60 years to achieve the necessary bark thickness to survive cambial injury in low-intensity fires

(Mcdonald, 1980). The requirement of such a timeframe prior to attaining fire resistance provides a difficult task for oaks when needing to recover from a high-severity fire, especially in areas facing heavy conifer encroachment.

The results of Nemens' study suggest that in many oak woodlands of California, one or two wildfires alone may not be sufficient in restoring oak populations to pre-fire exclusion numbers. The fire-free period needed by many oak trees to develop their fire resistance increases the risk of conifer encroachment and eventual canopy dominance. In areas already facing encroachment, there is potential for low-severity fires to further reduce oak populations; while in past historic fire regimes these low-severity fires would enable the survival of oak woodland ecosystems by preventing the growth of intrusive conifer saplings. Grady and Hoffman (2012) refer to this situation as a "fire trap", which is further complicated by the vulnerability of oak sprouts to reburns despite the resiliency maintained during initial high-severity burns.

Therefore, high fire frequency burns may act as oak suppression in many areas, instead of the primary mode of maintenance that mature oak woodlands experienced with historic fire regimes. While there can be some solace found in oak survival in the shrub form, this scenario minimizes the many wildlife benefits and necessary ecosystem services found only in mature oak woodlands.

6. Management Findings and Recommendations

6.1 Invasive Management Methods

The U.S. Fish and Wildlife Service recognizes three primary reasons why the management of invasive plants should be combined with fire management: 1) Fires can promote plant invasion. 2) Fire can be used as a tool to control plant invasions. 3) Plant invasions can affect fuels, fire behavior, and fire regimes (Brooks and Lusk, 2008). Given the great diversity of plant life California has to offer, the job of effectively managing the health of these ecosystems is one of constant vigilance and consideration of all aspects involved. It is unlikely that one method alone will effectively enhance the targeted landscape, so oftentimes the involvement of various measures over a space of time is necessary.

In this portion of the paper I will be exploring the methods that garner specific results, be it positive or negative. It will provide answers to which applications are most appropriate in which landscapes and the particular circumstances and confines of that application. The management methods of discussion are mastication and prescribed burning, with the shared target of reducing invasive populating while increasing native community presence.

As a method of evaluation and comparison, I completed a SWOT analysis for both management methods. The SWOT analysis identifies the strengths, weaknesses, opportunities, and threats of each method and helped shape my finalized recommendations. Both SWOT analysis can be found at the beginning of the two sections, as a way to summarize the findings expanded upon throughout each section.

6.1.1 Mastication

Mastication or mechanical mastication is use of bladed machinery to chew up vegetation and deposit the resultant materials in the form of mulch. The method has been utilized by the

NPS, Forest Service, and Fish and Wildlife as a method of reducing fuel loads and promoting a more natural landscape through the thinning of shrubs and small trees (Figure 19).

Figure 19: Photos of mastication and the resultant material debris (mulch). (Wilkin et al. 2017)

Mastication can be beneficial in providing greater forest health by replicating some of the reductionist effects of fire without burning the area. The treatment has been used by land managers as a way to remove invasive plant communities and encourage the establishment of native populations. While the process is crude and often involving of heavy machinery, proper application can offer reduced fuel loads and revitalized ecological balance, though there are limitations to the effectiveness of the process (Figure 20).

SWOT Analysis: **Mastication**

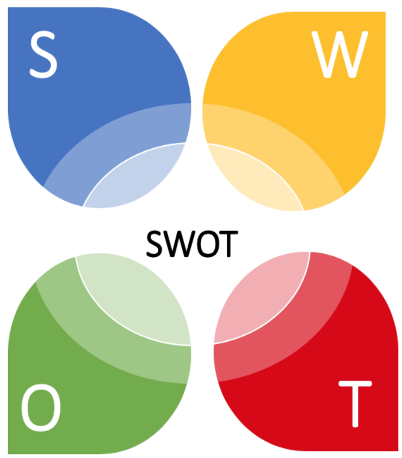
Mastication: the use of bladed machinery to chew up vegetation and deposit shredded material

STRENGTHS

- **Reduce large areas of invasive species**
- **High returns of native species**
- Can replicate some of the effects of fire without needing to apply it

WEAKNESSES

- **High yields of invasive plant species, especially annual grasses**
- Use of heavy machinery can have detrimental effects on local ecosystem such as erosional influences, soil compaction, and the transfer of invasive seeds



OPPORTUNITIES

- May promote native species that do not react well to prescribed burns
- Mulch material can feed soil and retain moisture

THREATS

- **May bring about higher invasive rates than if no treatment were applied**

Figure 20: "SWOT" Analysis of Mastication methods (Author)

In Wilkin et al. (2017), there was concern regarding mastication and its positive effects on invasive counts. Though the study largely focused on chaparral and shrublands, their findings regarding non-native density post-treatment offered great insight into the challenges of managing such areas. Both shrublands and chaparral occur in and around oak woodlands and conifer forests of the North Coast bioregion and their discovery that mastication yielded higher counts of non-native annual grasses was worrying.

The season of application can be very important since different plant species will be affected by specific timeframes of disturbance. In the case of mastication for Wilkin et al. (2017), the application season brought about reasonable differences in non-native annual grass density, with fall application producing higher counts than the spring (+4,200 more non-native plants present per square meter). While fall application brings out higher totals of non-native grasses, it may offer better fuel reduction potential, with longer lasting reductions in shrub-based fuels.

The study also observed that masticated areas were comparatively more vulnerable than fire-treated areas in the emergence of non-native annual grasses. Post-treatment, there was at least 10 years of non-native plant persistence within the masticated areas, compared to low presence and density of non-natives in the fire-treated spaces.

Potts and Stephens, 2009, focused on the reduction of fuels and the differing vegetative responses to such practices. Like Wilkin et al., 2017, there was agreement within their results regarding the high values of non-natives following mastication efforts (Figure 21). The abundance of non-native annual grasses was found to be 29 times greater after fall mastication than the lowest tested method of spring prescribed burns (spring mastication efforts returned 15 times higher).

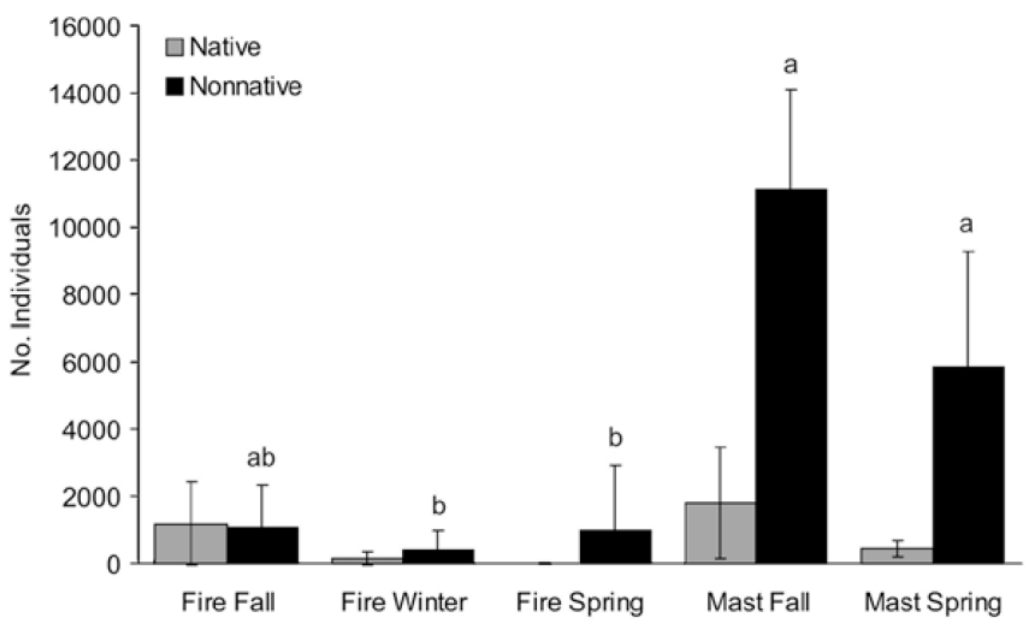


Figure 21: Bar graph representing the abundance of native and non-native grasses present following management efforts. (Potts and Stephens, 2009)

Despite the high totals of non-natives present following mastication there were surprising returns regarding native species counts. Mastication efforts offered 70% more individual native plants than any of the prescribed burns. This was particularly unexpected given the strong evidence of chaparral dependence on fire for propagation. Closer examination showed that there were 14 native species found only within the mastication zone, compared to 8 native species found only in the prescribed burn areas. It was discovered that each of those 14 species are commonly found in open, disturbed spaces, while the 8 natives from the burn zone were rather fire dependent.

Seasonality was not as influential in the representation of revegetation as was expected. While there was some seasonal variation among the prescribed burnings, it was not significant enough to acknowledge with further inquiry. Climate seasonality has a larger role in the recovery representation, with the high number of non-native species present after fall burns due to the timing of precipitation. With the first fall rains non-natives will immediately germinate and take over the treated space – germination occurs 2 – 3 months prior to that of native species.

In comparing the rates of shrub recovery, Potts and Stephens (2009) found that 3 years post-treatment yielded intriguing results. The masticated areas averaged 44% recovery compared to 71% in the prescribed burn plots. There is question whether the slower rates of recovery of the masticated plots are better suited for conservation efforts due to the more time spread in between treatments. This is doubtful though, because the less shrub cover will typically equate to higher coverage of non-native grasses and thus higher flammability within the space. There is also concern that the grass concentrations could lead to quicker spread of flames resulting in higher burn conditions as opposed to low to non-existent fire damage.

Mastication appears to offer increases in vegetative growth; however, the populations that it propels may be either native or non-native species. By adjusting the treatment by seasonality or applying treatment measures prior to mastication you can increase the likelihood of greater native species composition. Treatments such as targeted species removal or herbicide application can offer higher odds of native species recovery and reduce the likelihood of dispersal of invasive seed banks. It would be recommended that this method should be avoided in areas of high invasive establishment, not only due to its potential to increase invasive propagation, but the possibility of introducing seeds through the use of heavy machinery (Owens et al., 2015).

6.1.2 Prescribed Burning

Throughout time, prescribed burning has been used to fulfill many environmental needs across many different environments. The use of fire as a means of managing vegetation can be traced back to pre-historic times when its uses brought about improved opportunities in hunting and food production. The emergence of fire exclusion has complicated our relationship with fire, and severely altered the existence of many California landscapes as previous fire regimes were changed. Through prescribed burnings we hope to reconnect those fractured relationships and resume the historic interactions between fire and an ecosystem. The removal of invasive species through fire is another key component of prescribed burning, and an important method of maintaining historic fire regimes (Figure 22).

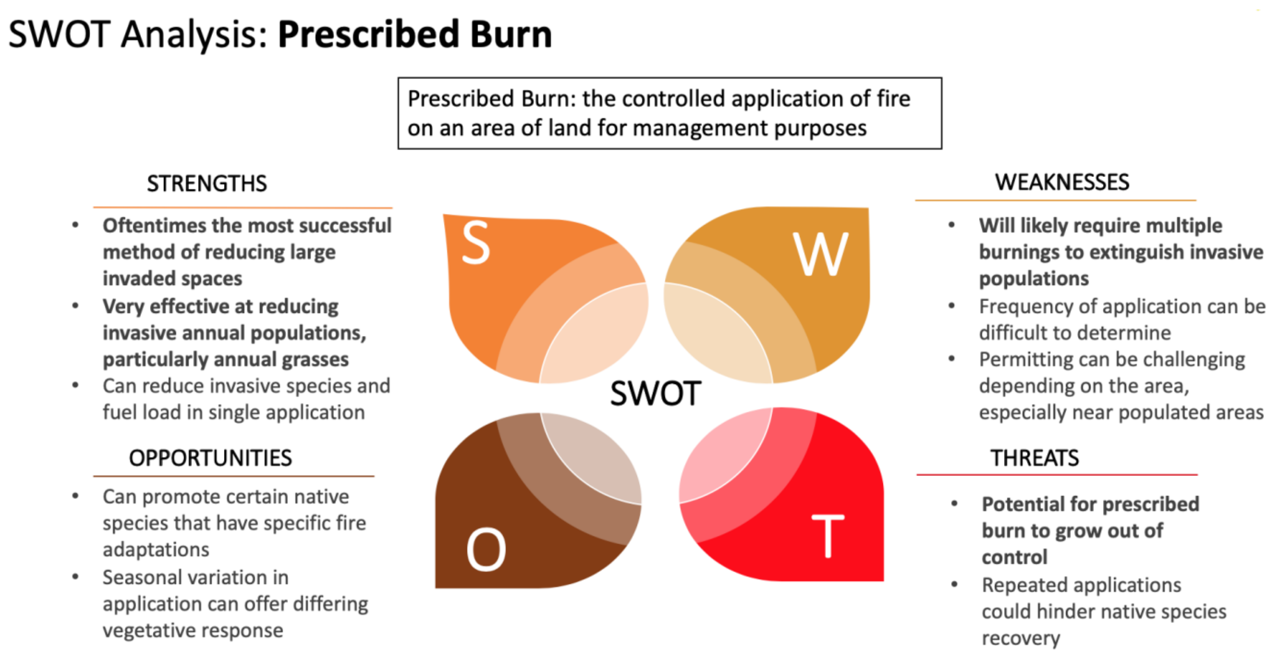


Figure 22: "SWOT" Analysis of Prescribed burning method (Author)

In managing invasive plants, we are aiming to accomplish the reduction of the invasive populations and the increase in desirable vegetation. To achieve this, a great deal of forethought is needed, especially with prescribed burns. The identification of specific objectives and anticipated outcomes is key to the initiation of fire application, especially the reaction of the targeted ecosystem to fire. With annual species being the primary invasive target for both oak woodlands and mixed conifer forests, my management recommendations will focus on them.

Prescribed burns are most effective at decreasing annual populations with short-lived seedbanks and flower structures within the fuel bed (DiTomasio et al., 2006). Yellow-star thistle and numerous annual grasses fall under this category and can be diminished with the use of a fire regimen. Multiple burnings will likely be necessary as a single burning will likely provide momentary reductions in populations, but not eradicate the invasion. It is essential that burnings occur before seeds become viable as this will reduce the germination of the plant by near 100% (DiTomasio et al., 2016)

The frequency of the burning is also an imperative piece to the correct application of prescribed burns. This will vary based on the area and landscape of application, as well as the species targeted to eliminate or preserve. Many annual populations, grasses and forbs in particular, are able to survive frequent burnings so long as their seeds are protected (Zouhar et al., 2008). This can also threaten perennial herbs who can see reduced establishments if frequent fire conditions are introduced.

For annual exotic grasses it is recommended to burn the area every 4 to 5 years. This timeframe follows the frequency of exotic grasses returning to pre-burn form within 4 years, allowing applied burns to negate the exotic presence. In reducing the invasive grasses native communities should be able to persist through the burns by setting enough seed to maintain their seed banks (Dickens et al., 2008) (Figure 23). The initial boost in forb populations after each burn declined as exotic grasses reemerged, lending necessity to the continuation of the burn regime.

Figure 23: Crew conducts prescribed burn to reduce invasive grass populations outside mixed conifer forest. US Fish and Wildfire Service (Brooks and Lusk. 2008)

In Sonoma County, DiTomasio et al., (1999) put a summer burn regime in place to control yellow starthistle. During the 3-year period only 8% of native populations showed population decline amidst high reductions in non-native species. Over 90% of the yellow-star thistle seedbank was eliminated in this time, with grasses and legumes filling in the burned areas.

Summer burnings can also increase the vegetation rates of native forbs. DiTomasio et al. (1999) also saw a 400% increase of native forb coverage, with particular benefit being seen in Fabacea and Geraniaceae families. The increase in forb coverage jumped from 17% to 67%, which helped boost plant diversity and community productivity.

Prescribed burns generally increase vegetative diversity and species richness, especially in native plants. The study DiTomasio et al. (1999) saw an initial decrease in purple needlegrass (Nassella pulchra) after the first burn, but subsequent years saw its coverage increase by 3x. Similarly, that study found that while a single burn did increase plant diversity, it was ineffective in reducing the populations of yellow starthistle, showing the limits to a single-burn strategy when dealing with invasive populations.

Klinger et al. (2006) found that species diversity and species richness totals showed no meaningful difference when compared between pre-fire and post-fire counts within the UMCF (Upper Montane Conifer Forest) and LMCF (Lower Montane Conifer Forest). This could mean that since there are minimal effects in invasive propagation post-fire, prescribed burns can be applied in these regions without much worry of introducing higher invasive species totals. Klinger concluded that prescribed fire use would likely not lead to large numbers of invasive species propagating nor the establishment of lasting populations.

The execution of appropriate application timing can be difficult to assess, but improper handling can increase invasive populations and create greater levels of disturbance. As evidenced in Keeley and McGinnis (2007), their attempts to reestablish historical fire regime in low-elevation conifer forests of Kings Canyon National Park led to an increased invasion of cheatgrass (Bromus tectorum). The study found that their application of prescribed burns was occurring too often to allow the necessary development of shrubs and the enhancement of canopy closure. The intensity of the burns also lacked the intensity needed to extinguish the seedbanks of the cheatgrass, leading to the conclusion that fire management for the area should apply burns at longer intervals. The aim would be to find an interval that provides coverage of both cheatgrass populations and fuel load buildups, ensuring protections of native populations and healthy forest structure.

The timing of the application can significantly impact the burn effect of plant populations, both invasive and native. Generally, species will suffer less harm if their lifecycle is completed prior to the burns, while those reliant on later flowering and seed production will see greater damage (DiTomasio et al., 2006). Late spring and early summer burns are most effective in reducing most invasive annuals and should be the primary period of application. This time period is also ideal for increasing native forb populations (Meyer and Schiffman, 1999).

Since very few invasive plants are eradicated by a single burn, long-term applications are often necessary and usually involve integrated approaches. In oak woodlands, burns should often be followed by herbicide treatment (Bernhardt and Swiecki, 1997). Post-fire herbicide treatments can be very effective at hindering the recovery of invasive species, especially if given a heavy establishment of yellow-star thistle or annual grasses (DiTomaso and Johnson, 2006). By applying the initial burn, you can activate the plant's seed germination and force the exhaustion of its seedbank. Once the seedbank has been depleted the seedlings can be destroyed through the localized application of herbicide. Herbicide treatment should be applied with care and conditional knowledge, avoiding applications prior to precipitation to prevent minimal effect and chemical movements into waterways and desirable plant communities.

Applying prescribed burns outside of the natural fire season can result in safer, more manageable scenarios for application; however, this may have inadvertent effects on vegetative recovery (Knapp et al., 2009). The burns may invoke different reactions in plant physiology and changes in competition patterns that may alter the efficiency of the application. Fall burns saw lower recovery rates for shrubs, with Winter and Spring bringing higher vegetative returns (Wilkin et al. 2017). Reductions in plant density were also found to be higher during Spring application, with some cases delivering semi-permanent reductions (Wilkin et al., 2017).

The interruption of fuel continuity is key to the reduction of fire frequency and coverage (Brooks et al., 2004). Cheatgrass (Bromus tectorum) can germinate in poor conditions and is able to thrive by filling in the spaces between trees and shrubs, thus extending the potential range of the fire. Additional measures can be put into place post-fire to encourage re-colonization of native species while deterring invasive movements. The adding of topsoil and seeding of native species along the edges of burn lines could boost population recovery while acting as a vegetative barrier for exotic movements (Dickens and Allen, 2014).

Though prescribed fire use is largely beneficial when applied within the confines of reducing annual invasive populations, these applications are typically followed by continual monitoring and retreatment. For the most effective results, an effective integrated management plan should be implemented to target the reduction of invasive species and the survival of native/desired species. Due to its effectiveness and the lack of viable alternatives, the use of prescribed burns should become increasingly utilized to decrease exotic species. A prescribed burn regimen is my top consideration for the treatment of invasive species in both mixed conifer forests and oak woodlands.

6.2 Management of Mixed Conifer Forests

There is growing concern that our forests need to increase the use of fire for management of fuels and vegetation (Franklin et al., 2006, Cocking et al., 2015, Lydersen et al., 2016, Steel et al., 2017, Collins et al., 2018). By increasing the low to moderate-severity fires that the forest type is accustomed to we can reduce the risk of future stand-replacing fires (Lydersen et al., 2016). Low to moderate-severity fires quickly reduce stores of surface content and ladder fuels, diminishing the damages to the forest structure in following fires (Agee and Skinner, 2005).

Since the North Coast has seen much in the way of fire exclusion, we need to understand the role of longer-term vegetation dynamics after an initial burn to see how this affects future fires of larger scale and intensity. As the predictive models tell (Lenihan et al., 2007, Steel et al., 2018), fire frequency will likely be increasing in conifer forests, but if our prescribed burns can decrease the intensity of those subsequent fires the forest structure can stand great benefits.

The restoration of natural fire regimes at some capacity is seemingly essential to the maintenance of mixed conifer forests. Many forests see significant departure from their historic regimes, leaving the ecological integrity of these areas at risk. Coppoletta et al. (2019) found that 76% of RNA's (Research Natural Areas) in California feature moderate to high removal from their historic regimes, with 87% of these burning less than expected (Figure 24). Many ecosystems that rely on frequent, low to moderate-severity burns are missing multiple fire cycles, often resulting in the burns that they do experience to be of higher severity than what the historical regime would entail.

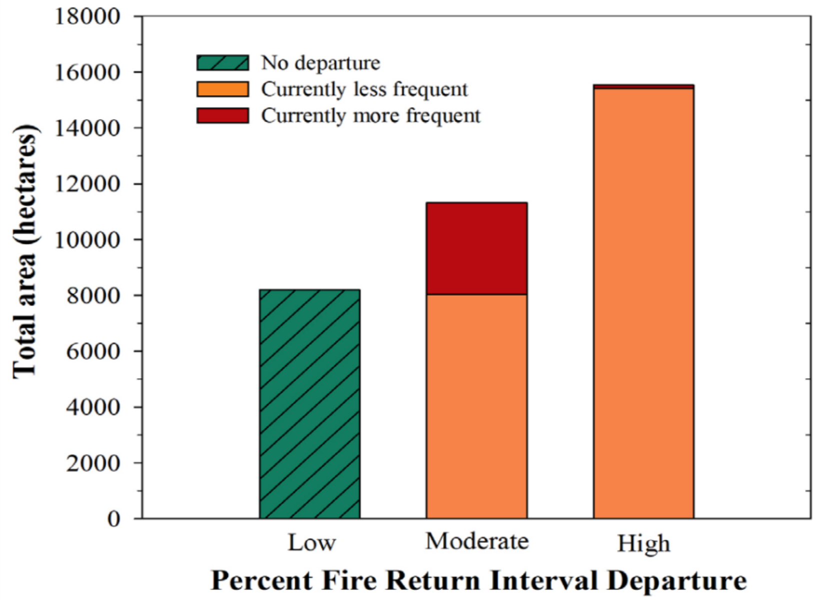


Figure 1. Estimate of percent departure in fire return interval for California RNAs. Departure is defined as low (0-33% departure), moderate (33-67% departure), or high (>67% departure).

Figure 24: Table showing the high amount of current displacement from historical fire regimes present in California RNAs (Research Natural Areas). Coppoletta et al. (2019)

With the greater amounts of fire-sensitive species present in mixed conifer forests we will see higher rates of reburn severity meaning even smaller-scale fires can have damaging effects on the canopy (Collings et al., 2018). This trend is probable due to initial low-to moderate-severity burns damaging the fire-sensitive species and then subsequent fires killing the weakened trees. While the fire-aided diminishment of the fire-sensitive conifers may be initially beneficial to the remaining historic conifer populations, it is unknown whether the scale of the loss of the fire-sensitive species would elicit regrowth in the more resilient species. The added biomass deposited by the dead trees would increase the total surface fuel loads, likely increasing future fire intensity and the risk of torching (Lydersen et al., 2016).

A number of studies have asked for a reclassification of “moderate severity” category of the RdNBR (Relative differenced Normalized Burn Ratio) by adding an additional class. While adding another class may not directly result in improved estimation of vegetative effects from fire, it can take individual trees into account as opposed to small groups of trees. It appears that given the adjustments and the updated data delivered we would be able to more aptly assess how forests are experiencing fires, such as the specific effects a particular species was experiencing. This information could enable forest managers to carry out more effective strategies if given a clearer picture on how a tree species will be affected by fire and thus affect the surrounding landscape.

The data that Lenihan et al. (2007) provides indicates the pressing need to rehabilitate our conifer forests. Each of Lenihan's model scenarios saw declines in conifer forest populations, with the highest losses experienced in simulations featuring increases in fire due to warmer temperatures and lower moisture. Extensive losses on average of 20% are expected as conifer populations are replaced by mixed-evergreens due to increases in minimum temperatures, with some scenarios predicted reductions as high as 51%.

Reseeding efforts will likely be necessary in areas that have experienced high-severity burns. Since successful seed dispersal in conifers rapidly deteriorates with distance from its source (Welch et al., 2016) it is unlikely that effective regeneration would occur under such circumstances. Shrubs and herbs can outcompete the surviving seedlings for light and water, meaning quick replanting and successive maintenance may be essential to the recovery of the conifer populations. Steel et al. (2018) found that mean high-severity area and high-severity core area have both increased over the 32 years of their study, a sign that the resiliency of these conifer forests is decreasing while fire severity appears to be increasing.

Additional research and monitoring of the interactions of forest types and fires is greatly needed. The complexity of such relationships presents a challenge to land managers and researchers alike, but through further investigations we will be able to accomplish more effective and encompassing management efforts. These new findings can function to develop strategies that incorporate the appropriate measures for restorative efforts, such as prescribed burns being utilized with the appropriate frequency and intensity in mind. Research topics such forest resiliency and species recovery after multiple fires should be areas of focus so we can expand our reforestation efforts and proactive maintenance based on new, insightful findings.

6.3 Management of Oak Woodlands

Like conifer forests, oak woodlands are in need of revitalization of historic fire regimes. While the avoidance of high-severity fire appears vital in the maintenance of conifer forests, the recovery of oak woodlands could very much benefit from the exposure to severe wildfire.

The methods of oak woodland restoration will vary depending on the severity of the encroachment. In early stages of conifer establishment prescribed burns can be used to diminish conifer saplings and maintain the open nature of the habitat. These fires should be applied routinely every 3 – 5 years to prevent conifer establishment and deny individuals the opportunity to mature into more fire-resilient forms. If the conifer establishment is further progressed (8-10 years), the individuals will likely hold some fire resiliency and have begun to contribute to fuel load changes, and restoration practices will need to shift to more mechanical techniques.

Tree removal will be necessary in the later stages of encroachment, likely requiring mechanical equipment or felling operations. At this point, the mature conifers are more resistant to fire, so small burns will do little to repair the previous habitat and may further damage or destroy the weakened oaks. Physical removal from the site will be needed to proceed with restoration, with smaller material being chipped for future application and larger pieces sold to help pay for the restoration costs (Cocking et al., 2015)

In areas where conifers have amassed very close to surviving oaks, girdling should be used to reduce the branch and bole injuries (Cocking et al., 2015). Girdling involves the complete removal of a thick strip of bark, splitting the vascular cambium layer causing the tree to die above the removed layer. This will effectively kill the conifer without risking oak damage from the fall of the tree and will open up the canopy as the tree decomposes.

The use of heavy machinery should be minimized when possible to reduce the amount of soil compaction and erosional influence, as well as the transference of exotic plant materials to the disturbed soils. Immediate rehabilitation of damaged soils inflicted by machinery should be carried out to reduce potential for erosional incidents or invasive movements. Wood chips and mulch from the smaller removed specimens can be utilized in this fashion to help insulate against further erosional degradation and invasive impacts.

Skinner et al. (2018) discussed the ability for oak populations to survive amongst (underneath) conifers as shrubs. The oaks can grow sturdy root reserves and survive through the continual development and dieback afforded by low-intensity fires. Low-intensity burnings are unlikely to return these smaller oaks to dominance and may hinder their development due to the high density and average height of the fir stands. With the large conifers able to survive smaller fires it might take a high-severity wildfire to replace the fir stands and offer oak re-establishment (Cocking et al., 2011, Nemens et al., 2018).

The high difficulty in prescribing a severe fire is a challenging obstacle in terms of managing extensive populations of oak recovery. Specific intensity thresholds must be met to guarantee eradication of the encroaching firs, as low-intensity fires may hinder the progress of the endeavor by removing fuels that could otherwise prompt high-severity conditions (Cocking et al., 2012). It remains to be seen how this situation can be replicated by land managers, but it appears wildfire is the only mechanism to provide the drastic ecosystem alteration needed to yield such sweeping results (Figure 25).

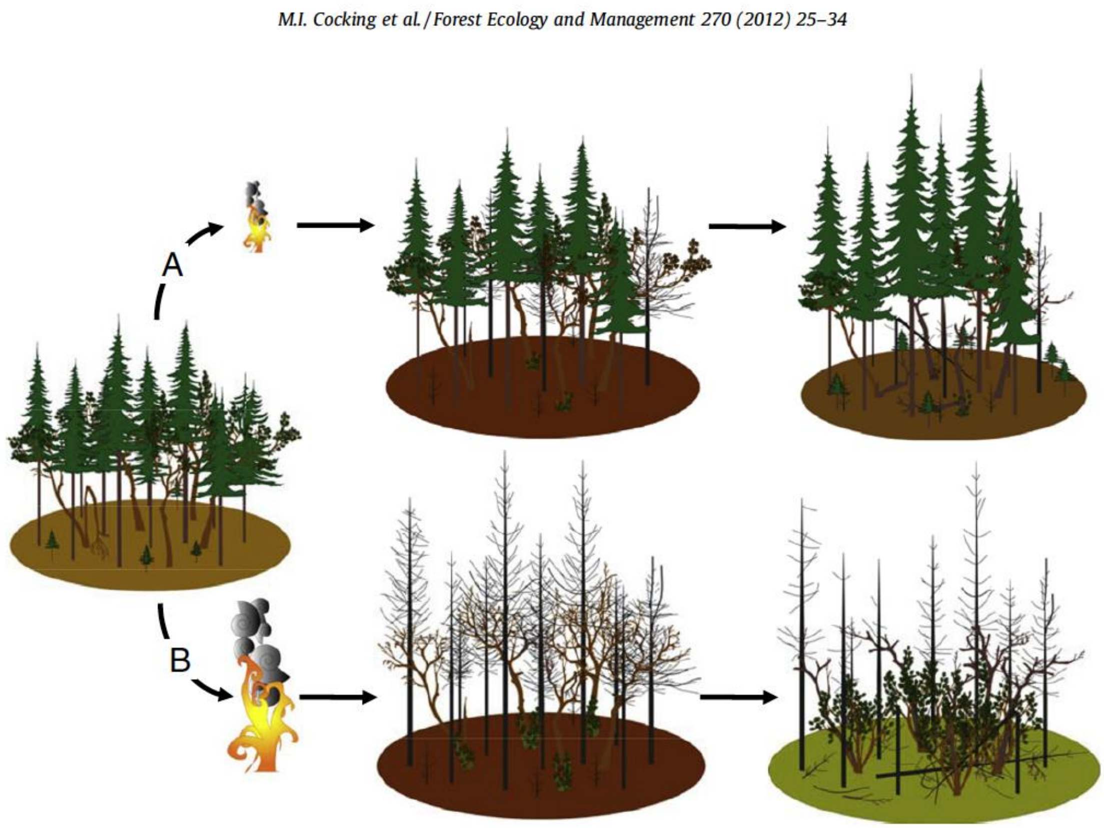


Figure 25: Model of how fire severity affected the encroached landscape. Small fires will maintain conifer dominance (A), while large fires will encourage oak recovery through destruction of conifer stands. (Cocking et al. 2012)

While Nemens' research shows that there is potential in severe wildfires undoing the impacts of lengthy fire suppression, it also concludes that the initial fire component may not be enough. It may be necessary to complete additional post-fire actions to break the cycle and protect recovering oaks from both conifer encroachment and severe burns. Restoration efforts of oak woodlands will revolve around the reintroduction of fire at various capacities depending on the situation of the site. Preparation of the site may be necessary prior to fire application to reduce the chances of oak mortality. Additional management practices should be performed to promote the resilience of the forest to wildfire through the reduction of shrub fuel loads, promotion of post-fire oak regrowth, and encouraging the increase in ecological diversity.

Seeing as the cost of restoration work will likely increase the further the conifer encroachment is allowed to progress; it seems most pertinent to implement efforts in a timely manner (Figure 26).The monetary benefits of preemptive or early management are a key component to project delivery, and the longer the project is put off, the greater the cost and the scale of the project will likely be. Furthermore, and arguably most importantly, earlier action can diminish damages to biodiversity and ecosystem services, whose decline could lead to further costs, in both financial and ecological standing.

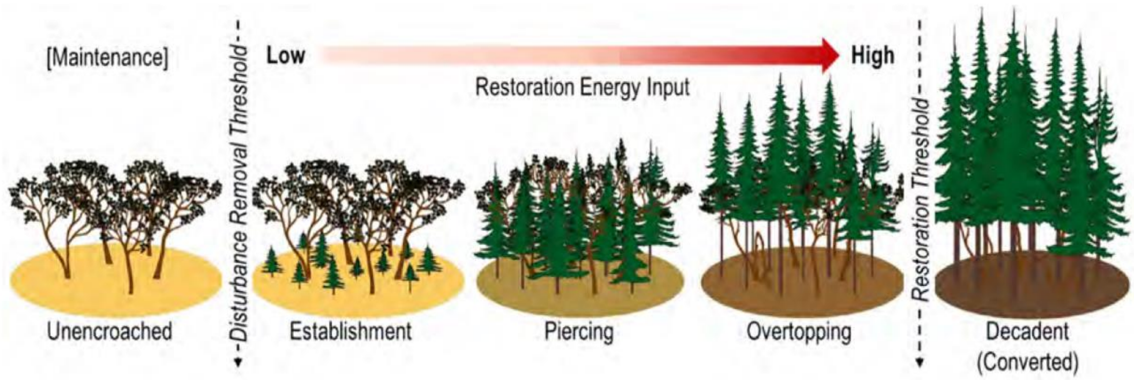


Figure 26: Model showing higher energy investment as encroachment progresses. (Cocking et al. 2012)

Preserving Northern California's oak woodlands will likely be difficult considering the current encroachment of conifer forests. The changes in fuel structure and reduced resilience to fire in the midst of conifer encroachment offer additional challenges to recovery or management of oak woodlands. Less focus should be invested into the sole importance of fire-intensity, as it is an oversimplification of a much more diverse problem. The effects of increased competition from the conifers as well as the resultant shifts in vegetation and forest dynamics need greater attention.

Similarly, additional emphasis needs to be placed on determining if repeat burns in recovering populations still allows oaks to recover. Though severe wildfires can prompt oak population recovery, we do not know how those young oaks will stand when facing future fires. Determining the likely outcome of subsequent fire exposure on oak saplings would enable managers to proceed with strategies to promote further fire exposure or practice exclusionary measures in the areas of recovery.

Additionally, more research is necessary regarding the limits of oak survival as a shrub beneath conifers. Finding out whether these stunted formations can reemerge as canopy trees if reintroduced to proper light conditions or whether their time in the shade has left their upward growth permanently compromised.

As Nemens concludes, “A species that is highly resilience to fire and drought, California black oak can play an important role in post-fire forest recovery, as it is not dependent on unreliable seed sources or seedling survival for regeneration. Management interventions will be of increasing importance in the context of predicted and on-going increases in fire size, frequency, and severity in California and the western United States (Abatzoglou and Williams, 2016, Westerling, 2016). “

7. CONCLUSIONS

Wildfire is an essential part of California’s ecosystem dynamics. When managed by Native Americans in the North Coast bioregion historic fire regimes maintained ecological functionality and landscape structure, but fire suppression and the spread of invasive species have interrupted those natural cycles. The alteration of these fire regimes can lead to reduced species heterogeneity and increased fuel loads, which result in larger, more devastating fires. The changes in fire regimes alter the way ecosystems interact with fire, replacing the benefits of the previous regime with forest destruction and biological disruption (Figure 27).

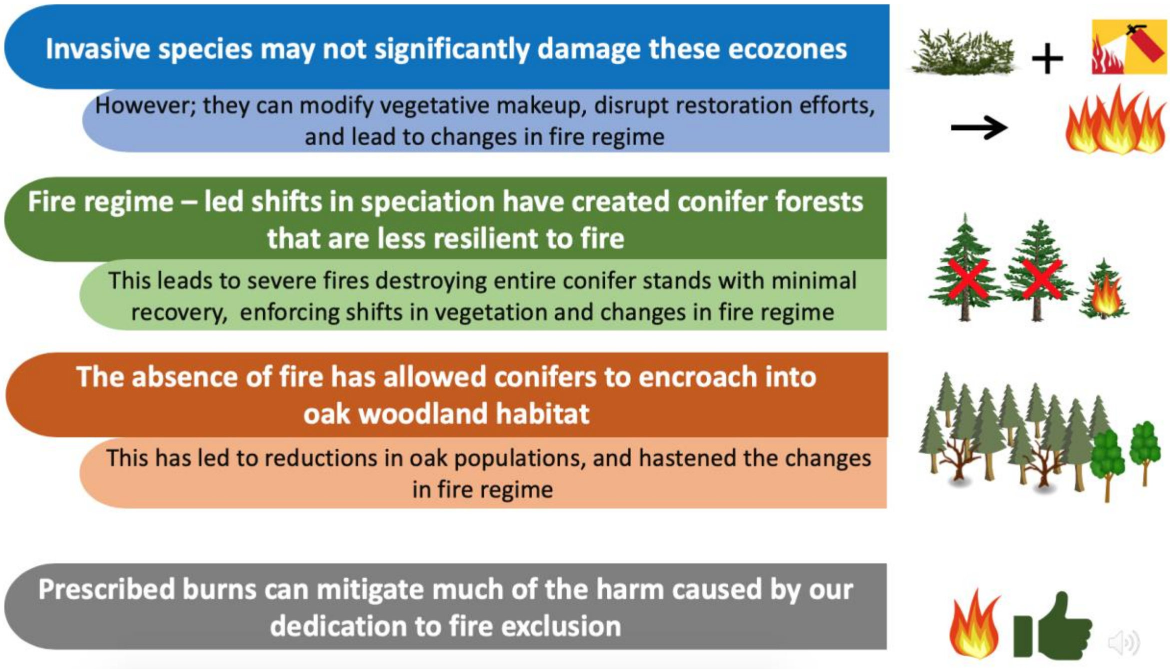


Figure 27: Summary of Conclusions (Author)

Ecological threats from invasive species pose problems to many areas within the North Coast bioregion, complicating the vegetative makeup and restoration efforts in these ecosystems. Critical conservation issues also arise in interactions between native species such as Douglas firs (Pseudotsuga menziesii) and California black oaks (Quercus kelloggii). The absence of fire has allowed conifers to encroach on the habitat of oak woodlands, leading to reductions in oak populations and the alterations of the ecosystem's fire regime that contribute to the shift from oak woodland to mixed conifer forests.

Disruptive transformations are also taking place within mixed conifer forests. From significant shifts in speciation and the buildup of high fuel loads, to sweeping regime changes and near-complete eradication of conifer stands, the outcomes of these alterations are dramatic and disconcerting.

While the complexity of forest dynamics is difficult to replicate, prescribed burns can assuage much of the harm caused by our dedication to fire exclusion. Reductions in surface and ladder fuel can reduce fire severity in conifer forests while promoting resiliency in its native inhabitants. The reproduction of historical fire frequencies can eliminate invading species and diminish conifer competition within oak woodlands, allowing oak stands to retake and maintain their valuable canopy structure.

There will be more questions than answers in the coming years as climate change continues to reshape fire patterns and vegetative landscapes. Conifer forests are perhaps the most threatened ecosystem in the western United States due to predicted increases in fire interaction, warmer temperatures, and increased susceptibility to exotic invasions (Brooks et al., 2004, Keeley et al., 2006, Lenihan et al., 2008, Keeley et al., 2011). The lack of historic fire intervals continues to put great stress on many oak woodlands, as without the inclusion of fire they are unable to utilize their resiliency or take advantage of the fire-sensitivity of the encroaching conifers (McDonald, 1980, Cocking et al., 2012, Cocking et al., 2015, Nemens et al., 2018). The recovery of oak woodlands is further complicated by the need for high-severity fire exposure to provide the widespread crown burns that would enable oaks to return as the dominant canopy species (Cocking et al., 2015, Nemens et al., 2018).

From Nemens et al., 2018) “The legacy of long-term fire exclusion in dry forests and woodlands, coupled with a changing climate, confounds efforts to restore historic landscapes. An increasing body of evidence indicates that changing patterns of disturbance are having lasting impacts on vegetation and fire regimes in many western US ecosystems”.

As climate predictions portend, old-growth fire-affected forests will likely see reductions in size and range due to the warming of the climate and changes in fire regimes (Keeley et al., 2011). The recovery of these forests needs an organized and optimistic approach, as there will certainly be shortfalls when dealing with a project with so many variables. Yet, swift action must be taken, as our inaction and past reservations about fire use have led us to this point, and further forest fragmentation is not an acceptable option.

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