FINANCING FUTURE FORESTS IN THE TAHOE-CENTRAL SIERRA

Photo Credit: Blue Forest Conservation

UC SANTA BARBARA
Bren School of Environmental Science & Management

BLUE FOREST
Financial Innovation for Sustainable Solutions

A Group Project submitted in partial satisfaction of the requirements for the degree of Master of Environmental Science and Management for the Bren School of Environmental Science & Management

by

LAUREL ABOWD

KIRSTEN HODGSON

BRENDAN MCGOVERN

TEAGUE TRAN

HANNA WEYLAND

Committee in Charge:
Charles Kolstad, PhD
Erin Winslow

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Dr. Phil Saksa, Blue Forest Conservation
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Erin Wilson, Bren School of Environmental Science & Management
Jacob Gellman, Bren School of Environmental Science & Management
Dr. Kristen Wilson, The Nature Conservancy
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Dr. Nicholas Povak, U.S. Forest Service
Gina Bartlett, Consensus Building Institute
Dr. Tessa Maurer, Blue Forest Conservation
Dr. Kim Seipp, Blue Forest Conservation
Angel Hertslet, The Nature Conservancy
Dr. Sarah Di Vittorio, National Forest Foundation
Megan Layhee, Calaveras Healthy Impact Product Solutions
Regine Miller, Calaveras Healthy Impact Product Solutions
Anonymous Survey & Interview Participants
The Dipaola Foundation

SIGNATURE PAGE

Financing Future Forests

As authors of this Group Project report, we archive this report on the Bren School's website such that the results of our research are available for all to read. Our signatures on the document signify our joint responsibility to fulfill the archiving standards set by the Bren School of Environmental Science & Management.

LAUREL ABOWD

KIRSTEN HODGSON

BRENDAN MCGOVERN

TEAGUE TRAN

HANNA WEYLAND

The Bren School of Environmental Science & Management produces professionals with unrivaled training in environmental science and management who will devote their unique skills to the diagnosis, assessment, mitigation, prevention, and remedy of the environmental problems of today and the future. A guiding principle of the School is that the analysis of environmental problems requires quantitative training in more than one discipline and an awareness of the physical, biological, social, political, and economic consequences that arise from scientific or technological decisions.

The Group Project is required of all students in the Master of Environmental Science and Management (MESM) Program. The project is a year-long activity in which small groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. This Group Project Final Report is authored by MESM students and has been reviewed and approved by:

DR. CHARLES D. KOLSTAD

DATE

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3. Acronym List

ACCG - Amador-Calaveras Consensus Group
CSV - comma-separated values
CWHR - California Wildlife Habitat Relationships
EIB - Environmental Impact Bond
ESG - Environmental, Social, and Corporate Governance
FRB - Forest Resilience Bond
GIS - geographic information systems
InVEST - Integrated Valuation of Ecosystem Services and Tradeoffs
NVUM - U.S. Forest Service National Visitor Use Monitoring Program
PUD - Photo-User-Day
RCP - Representative Concentration Pathways
SOFAR - South Fork American River Cohesive Strategy
TCSI - Tahoe-Central Sierra Initiative
TNC - The Nature Conservancy
USDA - U.S. Department of Agriculture
WIP - Watershed Improvement Program

ABSTRACT

Decades of fire suppression have altered the fire dynamics in California's forests, causing large and severe wildfires to erupt more frequently than ever before. These severe fires devastate ecosystems, threaten human lives and property, and damage forest ecosystem services–the monetary and non-monetary resources that communities receive from healthy forests. Forest restoration projects can mitigate the threat of severe wildfire and protect or enhance these resources, and California has developed an ambitious plan to increase the amount of acres treated annually in the state by 2025. However, restoration projects face numerous impediments, including lack of funding, which limits both the pace and scale of proposed projects. One avenue to increase the funding available upfront for restoration is through contributions from private investors. In Blue Forest Conservation's Forest Resilience Bond (FRB) model, these investors are repaid by local beneficiaries who value the decreased fire risk and enhanced ecosystem services yielded by successful restoration projects. Development of new FRBs requires an understanding of local beneficiaries, the ecosystem services they value, and the distribution of these ecosystem services across the landscape. In this study, we survey organizations in a portion of the northern Sierra Nevada, California to better understand their interests in forest restoration, perceptions of ecosystem services, and concerns about untreated forests within the region. Then, we model several focal ecosystem services in current and projected future conditions to discuss the impact of fire and/or restoration. This study provides a framework for exploring stakeholders and ecosystem services in a landscape, which can be applied to other locations during the development of future FRBs.

Key Words: Ecosystem services; Tahoe Central Sierra Initiative; Wildfires; Climate Change; Forest Restoration and Management; Forest Resilience Bond; Green Bond; Environmental Impact Bond

Photo Credit: Blue Forest Conservation

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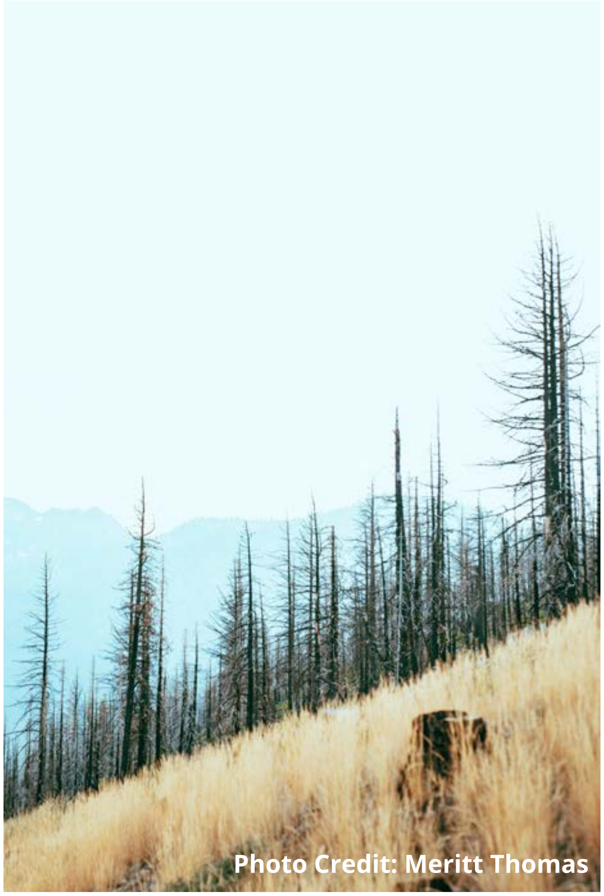
1.0 INTRODUCTION

The legacy of fire suppression has impacted modern forest structure, contributing to the escalating threat of wildfires across the western United States. In conjunction with the warming climate, wildfires are becoming larger and burning more intensely and severely (Van de Water & Safford, 2011). The combination of concentrated amounts of fuel, the presence of understory species, and the consequences of climate change have led to some of the most destructive fires in California's history occurring in recent years (California Department of Forestry and Fire Protection, 2022; Smith, 2021). The 2018 Camp Fire, which destroyed more than 18,000 structures and caused 85 deaths, is the most deadly and destructive wildfire in the state's history (Maranghides et al., 2021). In 2021, the Dixie Fire became the largest single fire ever recorded in California history, burning 963,309 acres and costing more than $630 million in fire suppression related expenses alone (Smith, 2021). Between 1985 and 1999, wildfire suppression cost the federal government an average of $425 million annually. In the 21st century (2000 to 2019), that average has risen to $1.6 billion annually (National Interagency Fire Center, n.d.). Without interval burning or treatment of the landscape, high severity wildfires will continue to become more common and cost the state billions of dollars in wildfire suppression efforts. As 2022 is shaping up to be yet another dry year for California, new management strategies that work proactively to prevent large wildfires are needed more than ever, especially in the Sierra Nevada.

Forest restoration projects can mitigate the increasing threat of wildfires by helping return forest structure to its historic patchy state, where fires are more likely to burn at low or moderate severity. Forests in the Sierra Nevada become more resilient to high severity wildfires when fuel loads are reduced in dense, overgrown, and unhealthy forests (Sierra Nevada Conservancy, 2017). Despite restoration's high potential for success, several barriers prevent it from being adequately utilized. The success of restoration projects requires a multifaceted approach that includes a strong scientific foundation, active community involvement, and generous financial support that is currently lacking (Quinn-Davidson & Varner, 2012; Governor's Forest Management Task Force, 2021).



1.0 Introduction

One avenue to decrease cost barriers to forest restoration is through conservation financing. Conservation finance offers opportunities for beneficiaries to contribute to restoration efforts that could lead to better forest management outcomes beyond what any one group can justify financing on their own. Distributing costs among beneficiaries within a treatment area can lower costs for individual beneficiaries while ensuring restoration objectives can be met across the landscape. Large scale restoration projects can be more easily funded by identifying companies, organizations, or government entities that understand the value of forest restoration projects and incentivizing their participation in cost sharing agreements for forest management treatments. These participants agree to repay investments in these projects which collectively leave beneficiaries better off. Bringing together numerous partners to fund, create, and implement forest restoration projects, Blue Forest Conservation's (Blue Forest) Forest Resilience Bond (FRB) aims to overcome the funding gap for forest restoration by utilizing private capital instead of public or philanthropic sources (Blue Forest Conservation, n.d.).

Motivating private organizations to engage in an FRB project requires knowledge about the ecosystem services that organizations value, an understanding of where and how much these services are provisioned in areas of interest, and an ability to persuade and incentivize stakeholders to fund restoration efforts that will provide a long-term return on investment beyond a monetary contribution. Connecting stakeholders to ecosystem services of interest and being able to demonstrate, quantitatively, how the supply of valued services will be impacted under current forest management practices can help motivate these groups to participate. To that end, this project seeks to understand both the perception of ecosystem services held by organizations and the actual distribution of ecosystem services in a portion of the central Sierra Nevada, called the Tahoe-Central Sierra Initiative (TCSI).

This project fills an urgent gap in current efforts to engage stakeholders about the importance of investing in restoration. Assessing the quantity of local ecosystem services, as well as their perceived value, will make our analysis more salient to investors, policy makers, and the local community (Mandle et al., 2021). By coupling a more traditional economic and biophysical ecosystem service assessment with stakeholder survey and interviews, we will strengthen the relevance of our resource assessment to policy and planning decision-makers in the TCSI.

The significance of this project extends beyond the central Sierra Nevada region as many other water-scarce and fire-prone regions monitor the success of Blue Forest's innovative financing and consider how similar mechanisms could aid their own large scale ecosystem restoration challenges. Our dual approach can provide a framework for extension of the FRB into other regions in the American west that also require accelerating restoration to reduce the threat of catastrophic wildfire.

To accurately capture the stakeholder perceptions of ecosystem services and their actual distribution in a single landscape for Blue Forest, the first objective of this project was to determine what ecosystem services community members value and where they would prioritize restoration efforts within the TCSI landscape. We achieved this objective qualitatively by interviewing stakeholders and having them prioritize and rank different ecosystem services, geographic areas, and restoration efforts. A second primary objective was to determine and locate key ecosystem services provided by the forests in the TCSI through the utilization of various modeling methods to quantify these ecosystem services under current conditions and two future scenarios: very limited future forest restoration work and complete forest restoration work. We created a suite of maps that will help natural resource professionals identify and consider important locations for forest restoration by comparing areas of stakeholder interest with the distributions of various ecosystem services within the TCSI currently and in the future.

From our analyses, we found that stakeholder interest broadly aligns with high-provisioning locations of water yield and sediment retention in the North Yuba region. While all ecosystem services we studied (water supply and quality, biodiversity, and recreation) will be impacted by climate change and different treatment scenarios, the impacts are not identical across ecosystem services. The modeling and stakeholder analyses can both be used to identify priority restoration areas within the TCSI, as well as to identify potential funding partners for future FRBs. Through restoration projects funded by an FRB, natural resource managers can better mitigate the potential damages of future fire within the Tahoe Central Sierra Region.


Photo Credit: Blue Forest Conservation

2.0 BACKGROUND

2.1 Fire in California Forests

Fire is an important natural disturbance and plays a critical role in regulating many of California's forest ecosystems. Low and moderate intensity fires help reduce forest fuels by burning young trees, understory species, and dead vegetation on the forest floor, allowing larger trees to continue to grow (Long, 2014). Many native plant species rely on wildfires to activate their natural growth or reproductive cycles (Silcox, 1911). Fire can trigger the release of seeds in species such as the Lodgepole pine (Pinus contorta), stimulate the flowering and fruiting of many shrubs and herbs, and alter seedbeds to allow germination processes to occur in Douglas fir (Pseudotsuga menziesii), Jeffrey pine (Pinus jeffreyi), and giant sequoia (Sequoiadendron giganteum) trees (Wright & Heinselman, 2014; Kilgore, 1973). Fires are also beneficial for rejuvenating terrestrial and aquatic habitats. Fires increase the availability of light, water, and nutrients by opening up canopies to light and providing a concentrated supply of nutrients found in the ash through the removal of excessive brush in these systems (Wright & Heinselman, 2014). Thinning of the forest landscape through fire has been shown to alter the local water budget by reducing canopy interception and transpiration demands of forests. Thinning due to fire may also contribute to modest increases in streamflow, but these effects depend on a number of factors including fire severity, catchment physiography, vegetation composition and regrowth, and soils and geologic conditions (Wagenbrenner et al., 2021). Low and moderate severity fires help to open densely vegetated lands, creating a patchy forest structure and allowing fire-dependent plant species important to the Sierra Nevada region, such as Jeffrey pine, to thrive (Dey et al., 2021, Taylor & Beaty, 2005).

Photo Credit: Matt Howard

2.1 Fire in California Forests

Prior to Euro-American settlement, fires occurred in California's forests both naturally and intentionally, through burns set by indigenous peoples. Cultural burning, recently defined as the "purposeful use of fire by a cultural group (e.g. family unit, Tribe, clan/moiety, society) for a variety of purposes and outcomes," has been an important component of indigenous cultural practices for thousands of years. Cultural burning protects and maintains the environment in line with tribal values, which are typically well-matched with the goals of ecological restoration projects (Long et al., 2021). This practice, in combination with natural ignitions, maintained patchy and resilient forest structure in the California Sierra Nevada for millennia.

Historically, Sierra Nevada forests burned every 2–20 years depending on the forest structure and species composition before fire regimes were disrupted by fire suppression (Taylor & Beaty, 2005). About half of the landscape would burn during this time, clearing the understory and rejuvenating the forest ecosystem. However, in the late 1800s, Euro-American settlers began to perceive wildfires as a threat to forest resources, in response to a series of massive wildfires burning throughout western states. These events had a profound effect on national fire policy, compelling forest managers to adopt fire prevention and suppression management strategies, such as the Smokey the Bear anti-forest fire advertising campaign and the 10 a.m. Policy that would ensure all wildfires were put out by 10 a.m. the day after they were reported (Dey et al., 2021). Over the following decades, forest structure in much of the west became overcrowded as understory species and young trees grew in the absence of frequent fires (Calkin et al., 2005). Currently, only about 0.2% of Sierra Nevada forests have burned at the historic interval, while 74% of forest land has not burned in the last 100 years (Taylor & Beaty, 2005).

Spending limited financial resources on fire suppression efforts limits the availability of state and federal resources which can be directed to restoration projects that are necessary to reduce the severity and intensity of future wildfires (Hjerpe et al., 2009). By focusing on upfront investment in forest thinning and restoration efforts today, this preventive strategy has the potential to break the current cycle of larger and more destructive wildfires plaguing the western United States. Restoration efforts that ensure forests are more resilient to future fires will save future suppression and management costs and reduce overall damages to important benefits provided by forest systems, while ensuring their continued existence and benefit to society.

2.2 Study Area: Tahoe Central Sierra Initiative (TCSI)

The Tahoe-Central Sierra Initiative (TCSI) is a partnership of state and federal agencies, non-governmental organizations, the timber industry, and researchers that was established to improve forest and social resilience to climate change and other stressors across the 2,417,632-acre landscape. The goal of this partnership is to increase the pace and scale of restoration thinning and prescribed fire across the watersheds of the central Sierra Nevada (Wilson and Manley, 2021). A memorandum of understanding to coordinate restoration efforts was signed in 2017 by the 8 project partners: The Nature Conservancy; Sierra Nevada Conservancy; California Tahoe Conservancy; National Forest Foundation; California Forestry Association; U.S. Department of Agriculture (USDA) Forest Service Pacific Southwest Research Station; University of California Natural Reserve System–Sagehen Creek Field Station; and the USDA Forest Service, including the Tahoe National Forest, Eldorado National Forest, and the Lake Tahoe Basin Management Unit (USDA, 2017).

The TCSI is a region of significant biological and economic importance to the states of California and Nevada. The region encompasses six watersheds: Yuba, Truckee, Lake Tahoe Basin, Upper Bear, North Fork American, and South Fork American. More than 105,000 people live in the TCSI with a number of towns and cities along Interstate 80 (Colfax, Nevada City, Grass Valley, and Truckee), Highway 49 (Camptonville, Downieville, and Sierra City), Highway 50 (Camino, Pollock Pines, and South Lake Tahoe), and Highway 89 (Sierraville and Meyers) (Wilson & Manley, 2021). The TCSI region includes all or significant portions of Sierra, Nevada, El Dorado, and Yuba counties; small portions of Amador, Plumas, Alpine, and Butte counties are also contained within the TCSI boundary in California. Portions of Douglas, Washoe, and Carson City counties in Nevada are contained within the TCSI boundary, largely within the Lake Tahoe Basin.

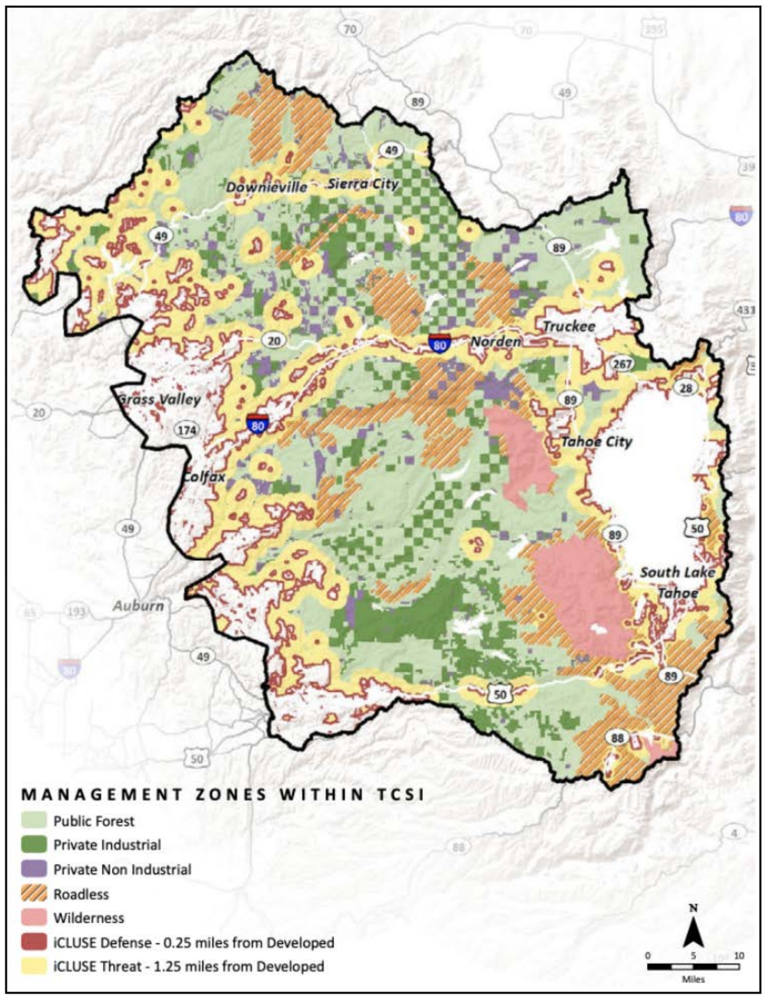


Figure 1. Boundary of the TCSI including the seven management zones within the landscape (Baribault et al., 2020).

2.2 Study Area: Tahoe Central Sierra Initiative (TCSI)

In response to increasing environmental and economic threats to the Sierra Nevada, the state of California signed the Sierra Nevada Watershed Improvement Program (WIP) into law in 2018. This partnership program unites federal, state, local, and private partners to restore the Sierra Nevada watershed and advance economic opportunities for the local community. The first WIP pilot project was implemented in the Tahoe Central Sierra Initiative (TCSI) and aims to increase the pace and scale of restoration through the development and use of innovative planning, investment, and management tools. The TCSI contains priority forests for California and is the site of several state and federal high priority restoration areas (Sierra Nevada Conservancy, 2020).

To facilitate the large-scale restoration of the TCSI, the region is divided into seven management zones: Public Forest, Private Industrial, Private Non-Industrial, Roadless, Wilderness, iCLUSE Defense, and iCLUSE Threat zones. These zones can be seen in the map above (Figure 1), and are used to determine where and how much restoration will occur on the landscape. Of note, the checkered areas are a mix of public and private lands known as the general forest management zone. The defense zone is a 0.25-mile spatial buffer established around developed areas which include urban, exurban, and suburban areas, and the threat zone is the same as the defense zone but with a wider buffer of 1.25 miles (Baribault et al., 2020). The various restoration scenarios used for planning in the TCSI are described later in this report.

The TCSI combines several public and private partnerships, along with cutting-edge science, to accelerate forest and watershed restoration. The TCSI is piloting the first-of-its-kind Roadmap to Resilience, a science-based approach to restoration that can be applied to the entire Sierra Nevada area (Sierra Nevada Conservancy, 2020). Blue Forest's success with its projects in the Yuba watershed indicates there is potential for larger-scale projects in the TCSI to benefit more stakeholders.


Photo Credit: Blue Forest Conservation

2.3 Forest Ecosystem Services

Forest systems in general provide a number of benefits that are necessary for human survival, such as raw materials (timber), air and water purification, water storage, and regulation of climate, among numerous other benefits. Goods and services provided by ecosystems that benefit human society at no extra cost are known as ecosystem services (Daily, 1997). A few benefits that forest ecosystems provide are listed below.

2.3.1 Climate Regulation

Forest systems are critical for carbon uptake and climate change mitigation. Carbon sequestration, or the capture and storage of carbon dioxide from the atmosphere (Manley et al., 2020), plays a significant role in forest ecology both as a source and sink of carbon dioxide. Through photosynthesis, chlorophyll in the leaves of trees captures carbon dioxide and reduces its concentration in the atmosphere. Trees continue this process as long as they grow; ultimately, when dead trees decompose carbon dioxide is released back into the atmosphere (Ryan et al., 2010). The impact of forest systems on climate regulation is thus complicated. However, it is estimated that the benefits provided from carbon sequestration equate to about $65 per ton, totaling $3.4 billion annually in the U.S. (Krieger, 2001).

2.3.2 Air Quality

Forests contribute to air quality in two primary ways: the removal of air pollutants when healthy and the addition of air pollutants when on fire. Air pollutants are defined as particulate matter or fine particles that become suspended in the air and contribute to poor air quality. Trees remove particulate matter from the air by absorbing these particles through small pores in their leaves and dissipating them within their cell structures (Nowak et al., 2006). However, smoke from high-intensity wildfires is a concoction of small particles less than 2.5 microns in diameter known as PM2.5. These particles are at least 30 times smaller than the width of a human hair and can enter the bloodstream and cause cognitive, cardiovascular, and respiratory impacts (Environmental Protection Agency [EPA], n.d.). Children, the elderly, and low-income people are most susceptible to negative health impacts from small increases in PM2.5; however, once PM2.5 concentrations reach unhealthy levels, all members of the public should reduce time outdoors (EPA, 2018). 40% of California's unhealthy air quality days from the last two decades occurred during the last five years, which coincides with the state's recent spike in extreme wildfires (Abowd et al., 2021).

Thus, to reap the air pollutant removal benefits of forest systems, low to moderate-intensity forest fires may be necessary to reduce the risk of high-intensity fires. While moderate-intensity forest fires contribute a small amount of PM2.5 to the atmosphere, they are critical for the avoided risk of much larger amounts of PM2.5 generated in a severe, large fire (Manley et al., 2020). One study estimated the air quality value of 500,000 mesquite trees to be $4.16 each, equating to $2.08 million (Krieger, 2001). Forest restoration and the use of prescribed burning thus provide value not only through the avoidance of high-severity fires, but also through improving the health of forests that contribute to air pollution removal.

2.3.3 Watershed Services

Forest watersheds trap and store water underground, contributing to the amount of freshwater available across the globe. Forests help purify water by filtering contaminants and other chemicals through their root systems (Manley et al., 2020). Water is required for all forms of life, thus it is important to protect the ecosystems that maintain our water availability and purity. Resilient forests help maintain a consistent water balance, while variability and susceptibility to flooding can be increased after a severe fire (Silins et al., 2009). The water flowing from forested watersheds is commonly utilized in many industries such as agriculture, electricity, and municipal water supplies. The productive use value of water flowing from forests is estimated to be $1.32 billion/year, most of which comes from agricultural use (Stewart, 1996; Krieger, 2001). In California, the Sierra Nevada provides about 60% of the state's water supply, which originates as snowmelt (University of California Merced, 2021). This natural water storage reservoir supplies water to nearly 23 million Californians as snowmelt flows downstream into streams and rivers for human use.

2.3.4 Biodiversity

The Sierra Nevada is one of the most biodiverse ecoregions in the United States, with high rates of species richness and endemism. More than 3,000 distinct species of vascular plants are known to inhabit the Sierra Nevada. The Sierra Nevada also hosts a variety of vegetation community types, including alpine meadows, mixed-conifer and single-conifer forests, and chaparral (Murphy et al., 2004). Many of the species found in the Sierra Nevada are endemic, rare, threatened, or endangered, primarily due to habitat loss and fragmentation, introduced pests and pathogens, and air pollution concerns (World Wildlife Fund, n.d.). Although it is not easily quantified, biodiversity is a critical ecosystem service. Biodiversity contributes to the stability of larger ecosystems, provides jobs and cultural connections, and can mediate the impacts of climate change-related natural disasters (Shaw, 2018).

2.3.5 Recreation

Forests provide numerous recreational and cultural values including but not limited to tourism, hiking and fishing, and important habitat for endangered or culturally important species. These values provide a range of leisure and recreational opportunities and experiences enjoyed by people. Recreation benefits people through improved physical health, psychological health, and emotional well-being. More recently, numerous studies have incorporated the complementary non-material benefits that enhance recreational opportunities, and include inspiration, cultural heritage, aesthetic, educational, and spiritual qualities (Hermes et al., 2018). It is estimated that recreational activities associated with national forests alone contribute between $12.5 and $110 billion annually to Gross Domestic Product in the U.S. and support 154,000 full- and part-time jobs. (Krieger, 2001; USFS National Visitor Use Monitoring Survey Results, 2020). The forests of the Tahoe-Central Sierra are popular destinations for camping, hiking, water sports, and alpine sports like skiing and mountain biking (North Lake Tahoe Visitors Bureau, n.d.).

2.3.6 Cultural Values

Cultural services that forests provide include aesthetic values, value based on forest longevity, and the knowledge that forests will provide value in the future. There is also value associated with the presence of particular habitats, such as old-growth forests that provide habitat for endangered species (Krieger, 2001). Additionally, the Tahoe-Central Sierra region is the ancestral and current home of the Washoe and Nisenan tribes, and is of great cultural value to these communities.

2.3.7 Resources

Forests are also the source of ecosystem services that are conventionally associated with economic value, here called resources. These resources include jobs, timber, and other economic goods that can be harvested from forests. Jobs associated with recreation are described in the recreation section above. Other industries that provide jobs in forests include fire prevention and fighting, restoration, and timber. Sierra Pacific Industries (SPI), the fourth largest lumber producer and third largest landowner in the United States, generates annual profits of approximately $375 million on lands in California, Washington, and Oregon (Sorvino, 2018). For the logging industry, the impact of fire is complicated; while SPI owns unburned forest that they manage for timber and desire to protect, they also profit from salvage logging of burned trees post-fire (Sorvino, 2018).

2.4 Impacts of Severe Fire on Ecosystem Services

Unfortunately, with more severe fires, the ecosystem services provided by forests are at increasing risk of being lost or damaged. For example, sediment runoff can increase significantly after a fire due to the loss of protective ground cover and stabilizing roots (Buckley et al., 2014). This runoff can degrade habitat for aquatic species such as the native California golden trout and lead to increased sedimentation in reservoirs, impacting water supply to downstream communities (Bladon et al., 2014). Healthy vegetation is also important in maintaining the water balance in a landscape and consequently the amount of water available for human use (Podolak et al., 2015). Large smoke volumes during a fire discourage participation in outdoor recreation, with potentially longer-term impacts to local recreation (Gellman et al., 2022). Lastly, fires threaten biodiversity in numerous ways, including direct threat to organisms, threat through habitat or resource loss, and landscape homogenization due to successional dynamics (Kelley et al., 2020). The immediate impacts of large and severe fires are especially felt by nearby communities. However, some–like smoke–can affect people living much further from an active fire. Distant communities can also be impacted by damage to forest ecosystems and the subsequent loss of ecosystem services.

2.5 Solutions to the Fire Problem

Forest restoration projects have great potential for preventing severe wildfire and protecting or enhancing ecosystem services. A recent example of the success of forest restoration in moderating fire behavior was the Caples Creek Watershed Ecological Restoration Project (Caples Project). During the 2021 Caldor Fire, which burned over 220,000 acres near South Lake Tahoe (Avitt, 2021), the Caples Project proved resilient to this intense wildfire as only the outer edge of the project site was burned. As the largest treated area in the Caldor burn area, the Caples Project provides important evidence to increase support for forest restoration projects in the future.

However, forest restoration is burdened by several major barriers that inhibit implementation at the necessary scale. Costs, legal, and time-sensitive considerations, as well as the sheer number of acres in California that need to be treated (1 million annually by 2025) are some of the major blockades to large forest restoration projects (Quinn-Davidson & Varner, 2012; Governor's Forest Management Task Force, 2021). Of particular importance is the availability of funds. Depending on the type of restoration planned and the condition of the forest, forest treatment can cost between $700 and $4,000 per acre (Bales & Conklin, 2020). Large-scale restoration projects can also require several years for completion, leading to funding uncertainty and overall higher costs. Additionally, much of the funding that is allocated to forest restoration is ultimately used to protect communities and human-made structures from active fire (Hjerpe et al., 2009). Ensuring that the necessary funding is available before a project begins can decrease uncertainty and time to project completion, but raising such large sums often requires additional sources beyond government grants and programs.

2.6 Forest Resilience Bonds

Blue Forest's first pilot project, the Yuba Forest Resilience Bond (FRB), launched in 2018 and is slated for completion in 2022. This timeline represents a decrease in time-to-completion of 65% compared to traditional restoration projects. This project raised $4 million in investments for 7,000 acres of forest restoration activities. The resulting restoration is projected to improve the resilience of the 15,000 acre project area. The 18 organizations who formally partnered with Blue Forest for the Yuba FRB are enthusiastic about its initial success and have agreed to a second project in the Yuba River district of over 48,000 acres (Blue Forest Conservation, 2021).

The FRB stems from pay-for-success financing mechanisms. First implemented to reduce juvenile recidivism in Britain, pay for success aims to shift the risk of intervention from the public sector to the private sector by hinging public investment on successful outcomes rather than number of treatments. Private investors pay the upfront costs of a public intervention through a Social Impact Bond (SIB). The program is monitored by an independent evaluator. If the program's predetermined metric of success, such as fewer repeat incarcerations or smaller pollutant loads, is met, the public entity will repay the private investors' investment, often with interest. If the metric of success is not reached, the public sector does not repay the investors and suffers no losses (Gustafsson-Wright, 2015).

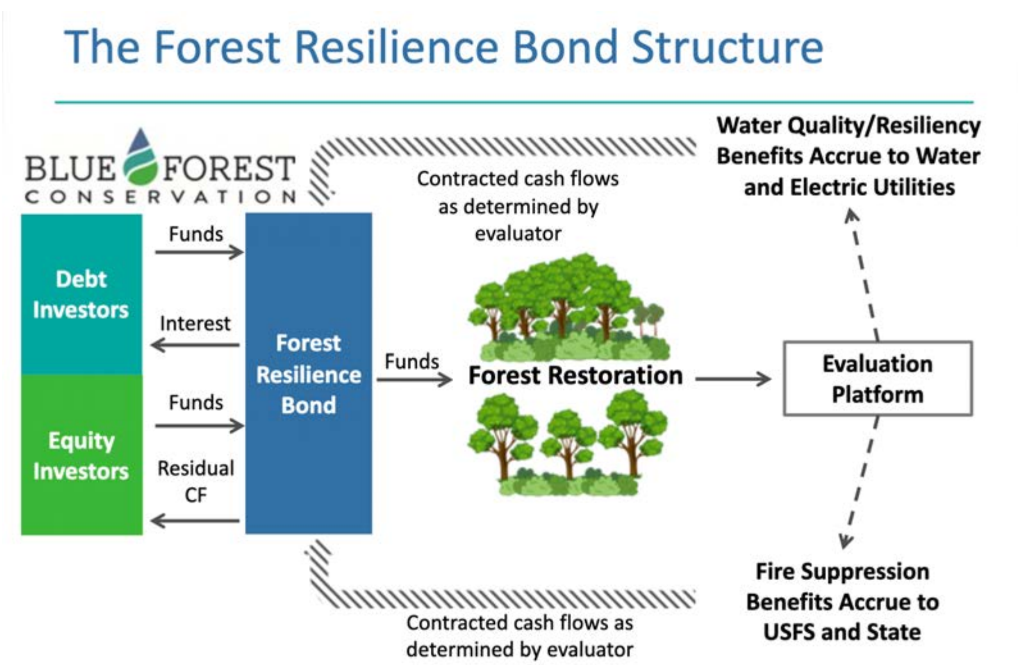


Diagram by Blue Forest Conservation

2.6 Forest Resilience Bond

While there have been over 60 social pay-for-success contracts, the first environmental pay-for-success contract occurred in October 2016 in Washington, D.C. as an Environmental Impact Bond (EIB). The DC Water EIB combats the city's notorious Combined Sewer Overflows (CSOs). The EIB seeks to slow down and prevent excessive runoff from causing CSOs by constructing 20 equivalent impervious acres of green stormwater infrastructure. Calvert Foundation and the Goldman Sachs Urban Investment Group are the investors providing the upfront capital. After project implementation, evaluators will track the volume of stormwater through sewers during large storm events to quantify whether the investments were successful. If the project is successful, DC Water and Sewer will repay the investors. If the project is not successful, the investors will not be repaid (Quantified Ventures, 2019).

As of 2021, three EIBs have been issued, including an FRB, and at least five additional EIBs are in development. Like Green Bonds, EIBs seek to advance environmental goals through private investment; however, EIBs are unique in that they specifically tie financial payments to the environmental benefits derived from the projects instead of to the implementation of a planned green project. By 2020, there had been over $250 billion in Green Bonds issued since the first introduction of the Green Bond in 2008. Given the EIB's similar potential for Environmental, Social, and Corporate Governance (ESG), EIBs could become another popular mechanism for green investments (Brand et al., 2021).

Each type of EIB is unique, and the FRB is no exception. To clarify, here is a simplified example for the use of the FRB: a private investor invests $1,000 in 100 acres of reduced wildfire risk over five years. If a pre-identified metric, such as the landscape's increased resilience to low-intensity fires or achieving specific treatment acreage milestones, is accomplished and met, the bond issuers, or beneficiaries, will pay the investor back $1,100. If the metric is not met, the investor is not repaid. Investors can include impact investors, insurance companies, and foundations. Beneficiaries who may be willing to pay to reduce the risk of fire include organizations who benefit from ecosystem services that are enhanced or protected by forest restoration, such as the state of California, fire safe councils, water agencies, utilities, or recreation organizations (Blue Forest Conservation, n.d.).

The FRB is also unique in that it seeks to handle larger projects than traditional pay-for-success contracts through coordinating multiple beneficiaries, instead of a single public entity. By grouping diverse beneficiaries of forest restoration, the FRB can sustain greater risk and size. This helps capture economies of scale, makes the project more efficient, and attracts more investors. Blue Forest launched the pilot Yuba FRB at a smaller scale and utilized fixed, contracted payments for environmental benefits instead of the pay-for-success format. Future, larger FRBs may incorporate pay-for-success, although the pilot project indicates that pay-for-success is not always a necessary component for a successful project (Convergence, 2020).

As excitement around using finance mechanisms to solve complex environmental problems increases, other localities are investigating the possibility of applying various mechanisms, such as the FRB, in their locations. For example, Colorado River Basin environmental organizations ranked a forest health environmental impact bond as high on impact, low on deal execution risk, and modest on financial return and necessary policy change as compared to other finance mechanisms. This makes the FRB a viable opportunity and further augments the support for a successful FRB in the Tahoe-Central Sierra Initiative (Culp et al., 2015). Blue Forest also has upcoming projects outside the state of California, such as the Snoquera Project in Mt. Baker-Snoqualmie National Forest of Washington state (Blue Forest Conservation, 2021).

While the Yuba projects identified some key ecosystem services and stakeholders, there are undoubtedly additional stakeholders, such as fire districts, that may have initially been overlooked. For FRBs to be successful, Blue Forest must identify beneficiaries of ecosystem services and reduced fire risk who are willing to repay investors over time.

2.7 Case Studies

According to a review by Mandle et al. (2021), there is a gap between ecosystem service assessment and policy action based on that assessment. To rectify this gap, ecosystem service science must align with an understanding of how these ecosystem services matter to different stakeholders within the local region. In fact, only 7% of the nearly 500 ecosystem service studies reviewed by Mandle et al. (2021) attempted to connect ecosystem service benefits to different demographic groups. In designing this study, we reviewed recent studies that surveyed populations to understand how they assign values to the ecosystem services that they care most about.

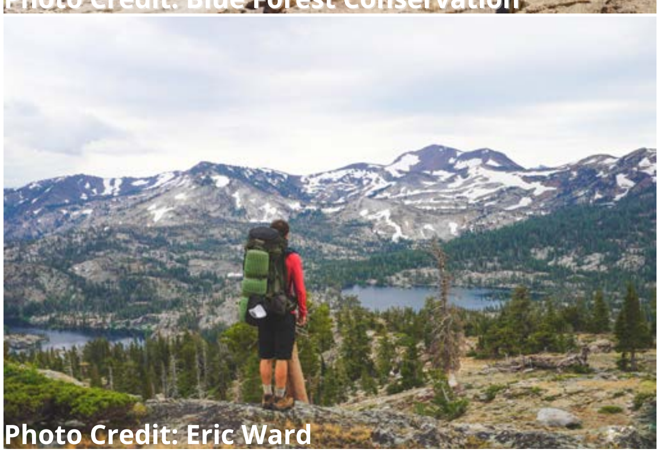
A number of studies have explored the relationship between ecosystem services and stakeholder valuation—both monetarily and non-monetarily—in environmental and natural resources management contexts. Drawing a link between the benefits of ecosystem services and a valuation from beneficiaries proves difficult to both capture and measure, and our project does not include extrapolating a dollar valuation. However, future projects by the client may be able to build upon our work. Identifying and assigning specific groups as stakeholders in a given environmental or natural resources management context makes this task more complicated. It is critically important to capture this input to ensure that local communities are given ownership, share the benefits, and are involved in decision-making (Millennium Ecosystem Assessment, 2005). These studies reveal that the process through which survey questions are designed, ecosystem services defined, and the value assigned is critically important to capture accurate stakeholder valuation. The literature suggests that it is easier to quantify ecosystem services that have a direct connection to monetary values and more difficult to quantify benefits that are enjoyed through cultural, spiritual, or other non-monetary forms of valuation.

Bryan et al. (2010) define the values, perceptions, and preferences individuals hold for ecosystem services as social values. In their approach, Bryan et al. (2010) attempted to target the management of ecosystem services based on social values within the South Australian Murray-Darling Basin region, Australia. Researchers interviewed 56 community representatives to determine and map their values for ecosystem services. The researchers utilized spatial indicators of abundance, diversity, rarity, and risk that were adapted from ecological science and applied to map social values for ecosystem services. Rarity was intended to capture uncommon or rare species to ensure conservation and maintain biodiversity. Risk was intended to account for species with a high likelihood of exposure to some process that might harm or contribute to extinction, therefore indicating higher priority. Areas with the highest social value abundance, diversity, rarity, and risk scores were defined as priority areas for the management of ecosystem services. Participants were allocated 40 green dots to assign places of positive values and 10 red dots to indicate threats or negative values. From there, researchers could overlap high social value across the indicators to identify the highest priority regions.

Another relevant survey assessed the social value that marine stakeholders assigned to the coastal area of northern Vancouver Island, Canada. Cultural services, such as spiritual value and sense of place, are often linked to individuals or groups, and researchers' ability to understand these values greatly benefits from interactions with specific stakeholders. The interview method included a spatial mapping exercise for the 30 survey participants, all of whom had livelihoods connected to the marine environment. Researchers used three broad categories related to ecosystem services: monetary value, non-monetary value, and threat. Researchers used this terminology for clarity and to avoid the jargon often associated with ecosystem service science. In individual interviews, participants were asked to circle areas on the coastal map of Vancouver Island for which they derived monetary value, non-monetary value, and which they viewed as threatened. Then, participants distributed 100 tokens between circled areas in a prioritization exercise. Some participants were unwilling to assign values due to concern over prioritizing different areas or not wanting to disclose areas of high personal value. However, most individuals participated in the mapping exercise. The researchers found that areas of high monetary value and non-monetary value overlapped. These areas also tended to be closer to towns, because these are places that the stakeholders accessed or were familiar with. This mapping method allowed researchers to directly connect social values for ecosystem services to explicit geographic locations (Klain & Chan, 2012).

2.8 InVEST Background

The ecosystem service analysis portion of this project partly uses Natural Capital's Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) software. InVEST is a suite of models used to quantify a variety of ecosystem services within a specified area in either biophysical or monetary terms under various scenarios. These ecosystem services include but are not limited to carbon sequestration, annual water yield, recreation, and even crop pollination–all of which constitute separate models within the InVEST suite (Natural Capital Project, n.d.). InVEST utilizes spatial data to locate ecosystem services in a study area and provides a valuation of each ecosystem service within the area as an output. Since InVEST can model various scenarios, it is an effective tool for exploring alternative situations and evaluating trade-offs and enables us to locate ecosystem services under our two future scenarios. For example, a recent study used InVEST and Natural Capital's Resource Investment Optimization System (RIOS) to compare various ecosystem services under five scenarios based on budget and climate change within the Truckee River Basin (Podolak et al., 2017). They then used the findings of the software, along with stakeholder input, to maximize the value gained from conservation investments. In our study, two additional ecosystem services were analyzed through alternative means due to a mismatch in our modeling goals and the outputs provided by InVEST. In addition to InVEST, ArcGIS Pro and regression analysis were used for further interpretation of important ecosystem services in the TCSI.



3.0 METHODS

3.1 Stakeholder Analysis Methods

3.1.1 Overview

The first objective of our project was to determine the ecosystem services that stakeholders value and where in the TCSI these services are valued the most. Our stakeholder analysis also helped us to determine where synergies and conflicts of interest may exist between stakeholders to promote conversation and collaboration. Our analysis was broken into a two-step process: first, a simplified summer online survey to allow for a higher response rate, and then, in-depth interviews with some of our survey participants in the fall. The more in-depth interviews allowed us to learn some of the reasoning behind the choices participants made in the survey and offered us the opportunity to use a more complex online mapping tool to collect spatial data.

3.1.2 Survey Methods

The goal of our stakeholder analysis was to identify stakeholders and link them to ecosystem services of interest, determine what they value, and identify where they perceive these services exist and are at risk within the TCSI landscape. To meet this goal, we created a survey and distributed it among stakeholders. We considered numerous approaches to best elicit data while designing our survey. We were particularly interested in capturing ecosystem services of value beyond traditional biophysical and economic values to develop a deeper understanding of local stakeholder interests across the landscape, which might be incorporated in future forest planning efforts (Bryan et al., 2010). We drafted and circulated survey questions with Blue Forest and iterated on questions and question types between June and July 2021. We were particularly concerned about capturing the perspectives of individuals that could adequately represent the diverse range of stakeholders that live and work within our study region, while still providing meaningful insight into the locations and characteristics of various ecosystem services across the landscape. Consequently, our sample frame was developed to consider the broad array of interests in ecosystem services throughout the region, represent numerous community and stakeholder perspectives, and focus on entities that could potentially contribute to a future FRB. For this reason, we defined our sample population as entities and organizations that operate within the TCSI and represent a diverse range of stakeholder groups including state and federal agencies, tribal communities, environmental organizations, fire-safe councils, business councils, and recreation associations. We excluded private individuals from our sample population while acknowledging that understanding individuals' ecosystem service valuations is important to developing a holistic understanding of community values around particular ecosystem services.

3.1 Stakeholder Analysis Methods

We defined stakeholders as individuals who participate in one or more of the various forest collaboratives within the TCSI region. These collaboratives include the Amador-Calaveras Consensus Group (ACCG), French Meadows Project, Lake Tahoe West Collaborative Project, North Yuba Forest Project, South Fork American River Cohesive Strategy (SOFAR), and the Yuba Forest Network. Our team decided to target these groups for two main reasons: (1) each collaborative is composed of stakeholders from local and tribal communities, fire-safe councils, the private sector, recreational associations, and environmental non-profits, as well as state, regional, and federal agency personnel and therefore represent the numerous organizations and interests that could express specific interest in ecosystem services, and (2) by targeting these collaboratives, we could leverage relationships with the organizers of these groups to directly distribute our survey to members and achieve a higher response rate than emailing individuals without context for our project goals. Targeting stakeholders within these forest collaboratives offered an opportunity to survey representatives and organizations actively aware of and working on forest management projects with knowledge of the numerous ecosystem service benefits, potential impacts, and threats to these benefits within our study region.

Our team selected SurveyMonkey as our online platform to disseminate the survey via email. We decided on this method over other options because we had envisioned using map pin question types available on the platform. This feature appeared to be more robust and better suited to our needs compared to Qualtrics. To assess preferences for various ecosystem services and the potential loss of services from disturbances like fire, drought, or pests, we utilized open-ended question types that asked respondents to write in responses to our five questions. We decided to avoid the term ecosystem services, which we believed might be too technical for use in a survey, and instead, used the term “forest benefits” to include the provisioning, regulating, supporting, and cultural services provided by ecosystems. Demand for ecosystem services was defined as the benefits received from healthy and resilient forests such as biodiversity, carbon storage, water supply, and forest products.

The first survey question asked respondents to list the five most important ecosystem service benefits that they receive from healthy and resilient forests that are most important to the mission and objectives of their organization. The second question asked respondents to list the highest risks from disturbances (i.e., fire, drought, pests) that would be most harmful to the mission and objectives of their organization. While open-ended questions are typically more difficult to analyze, we decided that this approach would allow respondents to articulate selections in a manner most relevant to their experiences and avoid forcing responses into predetermined categories. In creating an optional rank order question type, we were mindful to give respondents the option to list up to five of the most important ecosystem benefits and five highest risks to ecosystems from disturbance.

Next, respondents were asked to name the biggest threat to the forest benefits that they had listed in previous questions. Again, an open-ended question type was used to give individuals the choice of how to respond. A follow-up question asked them to explain their selection for the question. To determine the perspective of respondents another open-ended question asked respondents to describe how the impact of these threats could be effectively avoided or lessened. For this question, we provided a list of examples for respondents to consider including aspen restoration, defensible space around communities, forest restoration, forest thinning, meadow restoration, mine reclamation, no management, prescribed or cultural burning, and riparian restoration.

Lastly, participants were asked if they would be willing to participate in a short interview to discuss their survey responses and perspectives about forest health and resilience. We had been in conversations with Blue Forest and the U.S. Forest Service about the distribution of our survey. The Forest Service was interested in gathering more responses from a pairwise comparison survey that had already been distributed among stakeholders in the region to help prioritize their Pillars of Resilience within the TCSI. We agreed to attach their 10 comparison questions to the end of our survey and share our results with them.

To ensure that our survey questions were clear and concise, we shared several survey drafts with the survey design professor, Dr. Heather Hodges, at the Bren School of Environmental Science & Management. We similarly piloted the survey with a Blue Forest contact in the study region to provide feedback. Due to time constraints, and the relatively small sample size, we were unable to fully pilot the survey on a subsample of participants.

We relied on points of contact among the stakeholder groups to disseminate our survey to their stakeholder email listservs. Survey invitations were distributed in August 2021. Respondents were given approximately two weeks to complete the survey. Invitations and a reminder email were sent out by the points of contact for ACCG, Lake Tahoe West, North Yuba Forest Partnership, Yuba Forest Network, French Meadows Project, and SOFAR. Members of the team, along with Blue Forest staff, also attended an ACCG stakeholder meeting to introduce our study and encourage attendees to complete our survey.

Survey responses were analyzed in R through text analysis with the TidyText package. We analyzed responses categorized by importance across the benefits, impacts, and threats question types.

3.1.3 Participatory Mapping Methods

To achieve our goal of mapping the locations where particular stakeholders have a demand for ecosystem services across the TCSI landscape, we considered several approaches. Participatory GIS mapping has been used extensively to identify and map ecosystem services values among participants and has been an effective tool in numerous studies (García-Díez et al. 2020; Klain & Chan, 2012; Paudyal, 2015). Given the constraints of conducting meetings in-person within the study region, we decided against methods of in-person participatory mapping in which participants might be asked to draw locations on physical maps, which could be digitized using a geographic information system later (e.g., Klain and Chan, 2012). Instead, we evaluated several online participatory mapping platforms to identify a method that would be suitable for our purposes. After conducting a literature review on various techniques used to capture geographical stakeholder input and availability of options, we identified the Maptionnaire Community Engagement Platform (https://maptionnaire.com/) as the tool best suited to our needs.

Maptionnaire is a map-based questionnaire service that can be used to conduct surveys and gather real-time participatory data online. There were numerous benefits of utilizing this tool over other participatory mapping tools. The first was a low barrier to entry in designing an online map-based questionnaire with the functionality to capture polygon and point data from users in real-time. Second, questions could easily be associated with specific tasks to draw polygons or drop pinpoints within regions of interest. Third, compared to alternative options, participants did not need to sign up or create a profile to use the tool. This was seen as a large benefit to reducing any burden on participants that might hinder participation. Lastly, results could be easily exported into useful formats for analysis such as a CSV file or GIS shapefiles, which reduced the time necessary to process hand-drawn maps into formats that could be utilized in GIS.

To design our Maptionnaire questionnaire, we decided to ask respondents to identify themselves and their organization. This geotagged any responses to their data, which would be anonymized when processing. Throughout the interview, we asked participants to answer the questions from their organization's perspective rather than their personal perspective. Respondents were then asked to identify where the most important benefits from healthy and resilient forests exist. Participants were given the ability to draw a polygon over an area of interest, which would prompt them to answer an open-ended question asking which benefit is associated with this particular polygon. An additional open-ended question was included to give participants the option to list co-benefits that are received from this same polygon area. This process was repeated to identify areas where a disturbance would have adverse impacts on forest benefits and where a large disturbance (i.e. fire, drought, pest, etc.) would cause the greatest damage to the mission of their organization. Lastly, a question was included asking participants to identify regions where their organization would prioritize areas for forest management. Similar to previous questions, a pop-up box prompted respondents to indicate why they selected a particular area. Screenshots of the Maptionnaire map are shown in Figure 2.

Using this questionnaire allowed us to collect GIS data tagged with specific ecosystem service benefits, impacts, and threats over our study region along with GIS data specifying where and why respondents would prioritize management if given the opportunity.

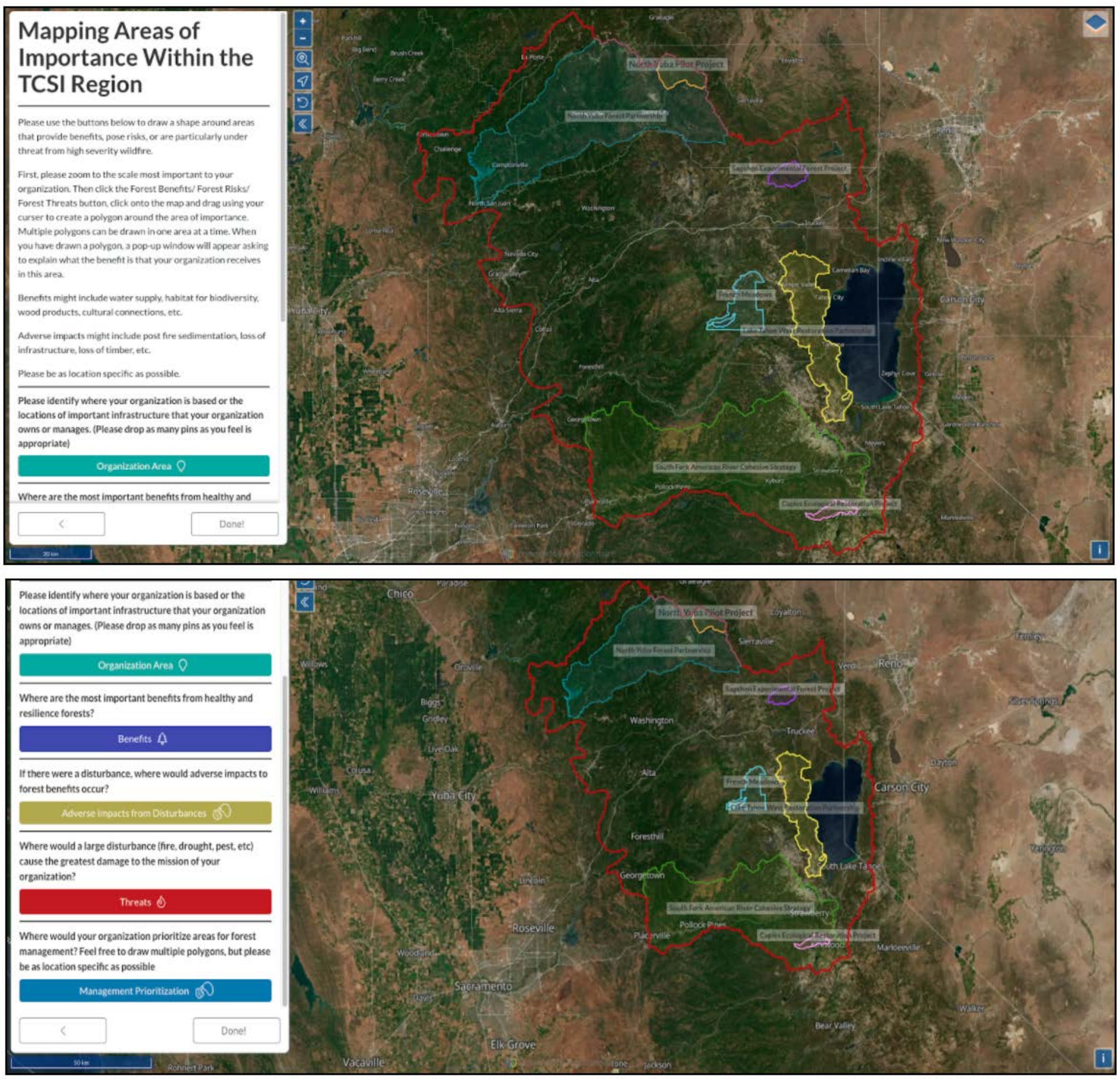


Figure 2. Screenshots of the online survey and the questions by category type. (Top) shows the initial instructions and information for selecting location type. (Bottom) shows the remaining questions.

3.1.4 Semi-structured Interview Methods

An important component of our data collection efforts was pairing participatory mapping data collection with semi-structured interviews of participants. This effort ensured that we could ask more specific questions about the reasoning behind the choices indicated on the survey and could ensure that participants understood what was expected from them in the participatory mapping component of the interview. To recruit participants for the semi-structured interviews and participatory mapping, we sent out invitation emails to the 32 respondents from our August survey that had indicated an interest in being contacted for a follow-up interview. Invitations included information about the format of the interview and that participants would need access to a computer and stable internet connection to conduct the meeting via Zoom. We decided to use Zoom in order to record interviews for transcription purposes and facilitate screen share capabilities to ensure that we could help participants navigate the tool if they ran into technical issues. Respondents were given a Calendly link to select their preferred time for a 1-hour interview. Of the 32 invitations sent, 19 participants were recruited for interviews with our team (response rate of 59%). We ensured that two interviewers were present for each stakeholder interview. One interviewer focused on facilitating the conversation, while the other took notes and followed up with any questions that might have gone unanswered during the conversation. Participants were asked permission to record their interviews for transcribing purposes only. Interviews were conducted in November 2021.

Our purpose in interviewing respondents was to ask more specific questions about their answers to the August survey, provide space for participants to elaborate further on the importance of particular ecosystem services to their organizational goals, and identify where these ecosystem services exist on the landscape. After providing an overview of our study aim, the interview purpose, and a brief orientation to the participatory mapping tool, we asked participants to describe their role and organization as well as their definition of the term, “healthy and resilient forests.” We felt that this was an important starting point for the conversation and to get respondents oriented to the following questions. Following this response, we reminded participants of their survey answers and asked them to elaborate on why these benefits were most important. Depending on responses, we asked each participant a combination of questions, including:

- Is there a way in which your organization tracks or measures the existence of these benefits across the landscape?
- Do these benefits vary to your organization spatially such as by location or geographically? Or temporally such as a different time of the year or day, etc? Over what time span?

- What is the particular reason you selected these benefits over others?
- How do you know these benefits are out there on the landscape?
- Is there an economic component to these benefits from the perspective of your organization?

Following this conversation, we asked participants to share their screen and draw at least 2-3 regions where their organization receives benefits from forests. This process was repeated for adverse impacts from disturbances and threat areas. Afterward, we asked respondents to describe why they listed their three selections during the survey. Depending on their responses, we would ask if there were spatial or temporal components to how their organization considers the impacts to ecosystem services. For example, we would ask if there was a spatial or temporal component to the services listed or a time when these services might matter more or be at greater risk. Following this discussion, we would ask them to map at least 2-3 areas where a loss of these services might be particularly harmful.

Next, we would remind them of which threat they listed on their survey. The facilitator would ask participants why this threat was greatest, which forest characteristics are most threatened or at risk from this threat, the main source of the threat, and their opinion on how to reduce the threat across the landscape. Following the conversation, we would ask participants to identify and draw polygons where their organization was most at risk from the threat listed. Each drawn polygon would prompt a participant to answer an open-ended question asking which threat exists in this particular region and why. Finally, we would ask respondents to describe management techniques that their organization would focus on if given the opportunity and to articulate why they would focus on these areas.

Spatial data from our semi-structured interviews was exported from Maptionnaire and analyzed in R. As participants identified their polygons of interest, we provided them space to specify what they were circling. This meant that a single polygon could represent multiple benefits, threats, adverse impacts, or priority management areas. For example, since our objective was to understand where in our study region were the greatest number of benefits, we needed to separate the multiple listed benefits and co-benefits into individual polygons for each benefit. This way, we could convert the single polygon shapefiles into stackable raster tiles and create a heatmap to count the benefits, threats, adverse impacts, or priority management areas within each 1000 m x 1000 m raster tile.

3.2 Modeling Methods

3.2.1 Overview

In order to estimate or quantify the ecosystem services deemed important by our stakeholders, a number of spatial analysis methods were used. We determined the four most important ecosystem services to model based on our survey and interview results. Stakeholders prioritized water quality and quantity, sediment retention, recreation, and general forest health as key ecosystem services. To analyze water quality and quantity, sediment retention, and recreation we utilized Natural Capital Project's InVEST model. In addition, the outputs from the recreation model were used to run a regression analysis. ArcGIS was used to analyze biodiversity as a proxy for general forest health to gain a comprehensive understanding of the quality of forest habitats in the TCSI.

3.2.2 Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST)

InVEST is a suite of 17 models, created by Stanford University's Natural Capital Project, that can be used to map and value ecosystem services. The InVEST suite of models can model ecosystem services including carbon storage and sequestration, annual water yield, and sediment delivery ratio (XinXiao et al., 2012). Each model uses spatial data and a number of parameters and provides results in either biophysical (e.g., sequestration rate) or economic terms (e.g., net present value of carbon sequestered). We used InVEST submodels to model the ecosystem services water yield and sediment retention. In addition, we used projected land cover changes to estimate these ecosystem services in current time (2020), and in 2040 and 2060 under two forest restoration scenarios.

InVEST is data-intensive and has particular requirements for each input data layer. We sourced our data primarily from publicly-available sources and processed them in ArcGIS Pro to meet the specific format requirements for each submodel, as described in Appendix A. Once configured appropriately, data files were uploaded into the submodel interface, parameters were input, and the model was run.

a) *Restoration Scenarios*

Water quality, sediment retention, and biodiversity were evaluated under different climate and restoration scenarios, using data provided by The Nature Conservancy (TNC). Land use/land change was modeled under climate projection Representative Concentration Pathway (RCP) 8.5. Using MIROC5, a hot and dry climate scenario, TNC ran LANDIS-II for six restoration scenarios to generate land cover projections from 2020 to 2100. For this study, we used the LANDIS-II outputs to analyze two restoration scenarios (1 and 6) for years 2040 and 2060, using 2020 as a baseline. The restoration scenarios are based on the management zones described in the Study Area section.

The data layers resulting from the LANDIS-II runs for scenario 1 and 6 were used as our land use/land cover inputs for InVEST. These layers originally contained detailed information on vegetation type, seral stage, and canopy cover for 14 land cover types, though barren, urban, lacustrine, and non-forest land cover represented no data spots in the layers. We further classified these groups for two of our modeling efforts, as discussed in Appendix A. Due to the nature of the LANDIS-II outputs, we considered a high change and low change version of each scenario. For the Annual Water Yield model, we also created versions of these land cover layers composed of a single vegetation type, to explore the influence of land cover type on water yield.

1. Annual Water Yield Model

a) *Data Inputs*

Water yield is a measure of how much water is available for use from a specific land area and is important for human consumption, agriculture, and hydropower production (Sharp et al., 2014). The InVEST Annual Water Yield model estimates water yield by subtracting estimated water output (through evapotranspiration, etc.) from water input through precipitation. The model does not differentiate between surface, subsurface, and base water flows. Instead, it assumes that all water that does not leave a watershed through evapotranspiration is ultimately available in water reservoirs (Sharp et al., 2014). The Annual Water Yield model utilizes several spatial data layers including precipitation data, land use/land cover data, and watershed data. Further details of the data layers and sources can be found in InVEST Annual Water Yield User Guide (Appendix A).

After the data layers were acquired, all the spatial data layers for the Annual Water Yield model were reprojected into Albers Conic Equal Area. Additionally, the precipitation, average annual reference evapotranspiration, root restricting layer depth, and plant available water content layers were each clipped to the study area boundary using a shapefile of the TCSI boundary, then resampled to a cell size of 30 m by 30 m to match the resolution of our precipitation raster. For future years, precipitation data was sourced from Cal-Adapt showing projected future precipitation as the 30-year average from 2035-2064 (Geospatial Innovation Facility, 2021). This data was processed in the same way as the current precipitation data. The watersheds layer was also clipped to the TCSI boundary. In additional runs, the modified land cover layers with a single land cover type were also used as inputs for the Annual Water Yield model.

b) Data Outputs

To illustrate the distribution of water yield across the landscape, we mapped the per-pixel water yield (in mm/pixel) across the TCSI for all scenarios. From a shapefile with water yield aggregated to the subwatershed level, we tabulated the aggregated (in cubic meters) and mean (mm/pixel) water yield for comparisons across scenarios.

2. Sediment Delivery Ratio Model

a) *Data Inputs*

The Sediment Delivery Ratio Model uses the Revised Universal Soil Loss Equation (RUSLE), to determine the movement of sediments throughout the landscape (Sharp et al., 2014). This includes information such as rainfall erosivity, which accounts for the intensity and duration of rainfall and the cover-management factor, which accounts for how land cover causes soil loss (Panagos et al., 2015).

As with the Annual Water Yield model, all inputs were reprojected to Albers Conic Equal Area. The rainfall erosivity index, soil erodibility, and watershed boundaries data were all clipped to the TCSI boundary layer. More information about the data needs for the Sediment Delivery Ratio can be found in Appendix A and the InVEST Sediment Delivery Ratio user guide.

b) Data *Outputs*

For further analysis, we used the sediment export output (raster), which quantifies the amount of sediment (in tons/pixel) that enters streams and waterways. We calculated the difference between current (2020) and projected (scenario 1 & 6, 2040 & 2060, high & low change) sediment export in the area using the Raster Calculator tool in ArcGIS Pro. We then used the Zonal Statistics tool in ArcGIS Pro to group and sum the sediment export layer by either HUC 10 watersheds or watersheds associated with a dam, which were manually created from altered watershed boundaries at the HUC 12 scale. This shows the difference (in tons/watershed) of sediment between current and projected future conditions.

3.2.3 Recreation Methods

a) *Literature Review: Impacts of Climate and Fire on Recreation*

During the semi-structured interviews and participatory GIS mapping, recreation was frequently mentioned as an important co-benefit of forest health and resilience in the TCSI. However, assigning an economic value to recreation that can be used to persuade beneficiaries to participate in an FRB remains difficult. To better understand likely trends in recreation in the future, we conducted a review of the literature regarding the impacts of climate and fire on visitation and recreation. Scientific literature analyzing the impact of climate or wildfire on recreation were reviewed for their findings. The outcome of this review motivated us to explore observable changes in visitation rates during an active fire in the TCSI, using the InVEST recreation model paired with a regression analysis.

b) Visitation: Recreation and Tourism Model

The InVEST visitation, recreation, and tourism model uses geotagged photos posted to the nature-centric photography website, Flickr, between 2005 and 2017 as a proxy for recreation visits to a geographic region in that time period. The model converts geotagged photos were taken by users and uploaded to the website Flickr into photo-user-days, which reveals concentrations of visitation across an area of interest. A photo-user day (PUD) at a location equates to one unique photographer who took at least one photo on a specific day (Sharp et al., 2014). The model accounts for users that post more than one photo per day to account for prolific users.

An area of interest shapefile can be uploaded into the model that bounds the geotagged photos retrieved from Flickr. For this analysis, a shapefile of the TCSI boundary was used. The model can be run by year or over a range of years to retrieve Flickr photo-user-days between 2005 and 2017. The user can specify the cell size output desired. Regression can be calculated using shapefiles or raster data of specific recreational areas to determine the relationship between Flickr data and the recreational sites. The regression models the relationship of PUDs to each recreational amenity. For our analysis, we are particularly interested in temporally assessing the impact of visitation during an active wildfire in our study region. A core component of forest health and resilience is reduced risk of catastrophic, large-scale wildfires. By explicitly connecting reductions in recreation to wildfires in the TCSI, a stronger evidence-based argument can be made for the needed increase in the pace and scale of forest restoration. Modeling the impact of an active wildfire on visitation rates and tying this explicitly to a decrease in economic activity could help persuade beneficiaries of the recreation economy to better understand the importance of proactive forest management to secure long-term economic resilience.

National forest visitation statistics are maintained by the U.S. Forest Service National Visitor Use Monitoring Program (NVUM), which uses surveys and visitor data to estimate recreation use at national forests. Beginning in 2005, the NVUM releases visitation results in five-year cycles (NVUM, 2020). Numerous studies have used the U.S. Forest Service's NVUM data as it is well regarded as the best visitation tracking available at national forests, and it utilizes a strong, scientifically-sound sampling approach (English et al., 2020; Rosenberger et al., 2017; Sánchez et al., 2021). The five-year survey is used to estimate visitation, demographics, and visitor satisfaction at national forests (English et al., 2020). However, social media data has become an increasingly popular way to investigate visitation at a finer spatial and temporal scale than the larger scale surveys conducted by national parks and forests (Sessions et al., 2016). For example, Wilkins et al. (2021) used geotagged Flickr data to investigate changes in recreation activity caused by summertime weather changes at national parks. They found that visitors tend to stay closer to infrastructure like visitor centers on rainy days, whereas on hotter than average days visitors tend to increase their elevation and their proximity to water bodies (Wilkins et al., 2021). Flickr data has been shown to be an accurate predictor of recreation (Sessions et al., 2016; Wilkins et al., 2021; Wood et al., 2013). Flickr photo data was compared to National Park Service (NPS) visitation data for 38 national parks in the western U.S. and, through multiple regression analysis, accurately predicted monthly

NPS visitation data. While Flickr data is biased towards certain demographics, years, and locations, it is on average highly predictive of changes in recreation activity (Sessions et al., 2016). Given the popularity of alternative photo-sharing platforms, Flickr's popularity has decreased significantly in recent years and this approach might not be useful for recent wildfire events. However, during the study period, Flickr was used widely and can provide useful insight into visitation patterns.

Given that our area of interest spans approximately 2.4 million acres containing numerous national forests, federal wilderness areas, California State Parks, cities and towns, ski resorts, lakes, and hiking trails, visitation rates for specific recreational sites are difficult to assess in absolute terms.

We retrieved photo-user-day data for each year with the TCSI shapefile uploaded as an area of interest for the available years within the model–2005 to 2017. We selected an output cell size of 300 meters. The resulting outputs are a shapefile with 300-meter cells with average PUDs per month and a CSV file with the same information. Each 300-meter cell is assigned a unique identifier (known as an FID), which we use to join multiple years of data to each cell. In total, the TCSI boundary results in 107,292 unique 300-meter cells (by FID), each containing monthly PUD averages for each year. After extracting this data from the recreation model, we used R to process the 12 years of PUD data into a single dataset for regression analysis.

To achieve this, we spatially linked PUD geocoordinates to shapefiles of important recreation and tourist sites. We included polygon shapefiles of federal wilderness areas, Lake Tahoe buffered to 75 meters (to account for recreational activity along the shoreline), hiking trails buffered to 10 meters, ski area points buffered to 1.5 kilometers, federal recreation points (data comprised of campgrounds, picnic sites, boat ramps and observation points), highways buffered to 10 meters, lakes (other than Lake Tahoe) buffered to 30 meters, and towns to account for photos taken along shorelines, within ski areas, and adjacent to roads and trails (Keeler et al., 2015; Cunha et al., 2017).

We assigned a value of 1 if the recreation layer of interest overlapped with the centroid coordinates of each PUD cell and a value of 0 if it did not overlap with the centroid. We also calculated the distance of each PUD cell to the nearest federal recreational opportunity. We were interested in measuring any noticeable decrease in visitation because of a wildfire. Given the popularity of Flickr and the history of wildfire in the TCSI, we selected the King Fire, which burned approximately 97,717 acres between September 13 and October 31, 2014, as a case study to measure visitation rate impacts from an active wildfire using our model. To capture impacts to a region in close proximity to the fire, we used a shapefile of the King Fire perimeter with a 30-kilometer buffer. A value of 1 was assigned to PUD cells that overlapped with the buffered King Fire polygon and a value of 0 was assigned to those that did not overlap. We then read in each year of PUD data from 2005 to 2017 and combined it into our data frame. As we were interested in measuring any observable change in visitation rates while the King Fire was actively burning, we added a value of 1 if a PUD cell contained a portion of the King Fire while it actively burned in September and October of 2014 and a 0 if a PUD cell did not meet that criterion. From this data frame, we conducted a regression of the PUDs on recreation locations, the active King Fire perimeter with a 30km buffer, and the twelve months after the King Fire was extinguished to measure any impacts on visitation.

To study the effect of the King Fire on recreation activity, we run the following regression:

$$y_{imy} = \alpha \text{ king\_fire}_{imy} + X_i'\beta + \phi_i + \delta_m + \lambda_y + \varepsilon_{imy},$$

where y_{imy} is equal to the PUDs of FID cell *i* in month *m* in year *y*. The variable king_fire_{imy} is an indicator equal to 1 if the FID cell *i* was within 30 km of the King Fire while actively burning. X_i includes FID-specific factors associated with each recreation layer. For example, wilderness_i is an indicator equal to 1 when the FID cell is within a wilderness area. Dist_rec_opp_i indicates the distance to the nearest recreation opportunity. Dist_rec_opp2_i allows for distance to affect PUD non-linearly. Any variable in *Xi* that is time-invariant is excluded from regressions that include Φ_i since they would be exactly correlated with the FID-specific fixed effect. Φ_i are the FID fixed effects which are indicator variables for every FID point in the sample. These control for time-invariant, location specific unobservable factors that could bias other coefficient estimates. δ_m accounts for month fixed effects and are indicator variables for every month. This variable controls seasonal factors. λ_y are year fixed effects and are indicator variables for every year. Year fixed effects should capture the effect of any one particularly busy or non-busy year within the TCSI. An error term ε_{imy} is included and clustered at the level of the FID point, which allows for arbitrary correlation in the error for the same FID point. We consider the years 2008 - 2017. FID points that never contained a PUD >0 were excluded.

Finally, we used a regression to measure time-varying effects of the King Fire by using lead and lag months before and after the fire. Using this "event study design", we sought to measure if any long-lived effects on visitation following the fire could be observed in the PUD data that might reveal a noticeable decrease in visitation.

$$y_{imy} = \sum_{-L \leq k \leq L} \alpha_k \text{ king\_fire}_{i,m-k,y} + X_i'\beta + \phi_i + \delta_m + \lambda_y + \varepsilon_{imy}$$

In this equation, k represents the leads and lags up to L time periods. For our purposes, we were interested in restricting L to 12 months before and after the King Fire. We expect coefficients before the event (where the event occurs at k = 0) to be null since the King Fire should not have an effect on visitation before it occurred. If any long-lived effects of the wildfire exist, then αk measures the effect k months after the fire. If αk is null, then there are no long-term effects.

3.2.4 ArcGIS: General Forest Health (Biodiversity)

Biodiversity was chosen as a proxy for general forest health and resilience. Biodiversity is a good indicator of forest health with increasing evidence suggesting a positive relationship between biodiversity and many ecosystem services (Brockerhoff et al., 2017). In order to assess general forest health, current land use (2020) and future land use (2040 and 2060) were compared under the different restoration scenarios and projected climate to determine where and how much forest types would change in the future. Conversion from one forest type to another would result in either a loss or gain of a particular habitat, affecting the biodiversity and resilience of the landscape.

Although there is no formal definition, forest type conversion (forest conversion, type conversion, etc.) implies major, extensive, and enduring changes in dominant species such as a change from one forest type to another or from forest to non-forest vegetation (Coop et al., 2020). Fire-driven forest conversion can have severe consequences as mature forests can be removed from a landscape or inhibit recovery mechanisms due to severe and frequent fires. Forest conversions are also associated with the resilience of the landscape and therefore the health of forests. In order to visualize where these forest conversions would occur on the landscape, processed land use layers for 2020 (Appendix A), 2040, and 2060 were converted from a vector to a raster using the Polygon to Raster tool in ArcGIS Pro. Then, using the Combine tool, the 2020 raster layer and the 2040 raster layer were combined into one raster layer. This step was repeated for the 2060 raster layer and for each restoration scenario. The top ten greatest forest type conversions by cell count were extracted based on the number of cells that changed (or did not change) from one forest type to another using the Extract by Attribute tool. There were over 100 forest type conversions for both scenarios in 2040 and 2060. Extracting the top ten conversions allowed for a clearer analysis, with the majority of the changes occurring within the top ten conversions. After extraction, the new raster layer displayed only the top ten forest type conversions between 2020 and each future scenario. The symbology and legend were changed to display the names of the forest type conversions based on their counts.

The attribute table for the combined raster layer showing the changes in forest type between 2020 and 2040 (or 2060) for each scenario was exported and imported into

R for further analysis. The original raster layer provided by TNC included codes corresponding to the California Wildlife Habitat Relationships (CWHR) System from the California Department of Fish and Wildlife. These forest codes were translated into the corresponding forest type names in order to summarize which habitats stayed the same in 2040 (or 2060) and which changed in 2040 (or 2060). A new column was created using the mutate function in R to display these changes in forest type (Appendix B).

After the initial processing, each forest type was analyzed in order to calculate net change between current (2020) and future land use (2040 and 2060). All of the data analysis was performed in R. A link to the GitHub repository is in the appendix. Overall, if a forest species converted to a specific forest type in the future, it was considered a net gain. For example, if Aspen in 2020 turned into Douglas fir in 2040, this was an overall net gain for Douglas fir habitat in 2060. An example of a net loss of Douglas fir is if Douglas fir in 2020 was converted to Sierra mixed conifer in 2040. The overall net change in forest type was calculated in R by first converting cell count to acres and grouping the forest types by current land use for net loss or future land use for net gain, then summing the acreage for each forest type. Net change was calculated by summing net gain and net loss. Next, total area for each forest type was calculated by summing the acreage of net gain and no change, where no change was identified as cells where forest type stayed the same between current and future land use. Finally, percent change was calculated by dividing net change by the sum of the total area for each forest type in 2020. Total area for each forest type was found by grouping together the forest types in 2020 and summing the area. Further details, including the code, can be found in Appendix B.

3.2.5 Interview and Modeling Results Overlays

After completion of our other analyses, we overlaid the results for water yield in 2020 with the identified water supply benefit locations from our interview process. Areas of high modeled water yield were symbolized in darker blue, and the shapefiles from interviews were added as an overlay in light orange with 86% transparency. We also added the locations of the top 20 largest dams (by reservoir capacity) within the region to compare stakeholder-identified water yield with reservoir location.

4.0 RESULTS

4.1 Stakeholder Analysis Results

4.1.1 Survey Results

In total, survey invitations were distributed to 583 recipients. The responses received are recorded in Table 1. Although 64 people started the survey, we only received 46 completed responses (7.8% overall response rate). A "response" was recorded even if respondents did not answer every survey question or indicated discomfort with ranking ecosystem services. When asked to identify which forest collaborative they represent, several participants specified membership in multiple forest collaboratives or indicated other affiliations. Of the 46 completed surveys, 32 respondents expressed interest in participating in a follow-up interview to discuss their responses in greater detail.

Table 1. Stakeholders invited by points of contact to take surveys. It is assumed that all email addresses are active and that no email addresses resulted in bouncebacks. Several respondents list multiple affiliations or "other" and therefore are overcounted in responses received.

Stakeholder Group (within TCSI)	Survey Invitations Distributed	Responses Received	Response Rate % by Group
ACCG	160	11	7%
French Meadows Project	19	8	42%
Lake Tahoe West	39	10	26%
North Yuba Forest Partnership	48	12	25%
SOFAR	317	6	2%
Other	NA	17	NA
Grand Total	583	64	NA

We asked survey participants to list and rank the five most important benefits from healthy and resilient forests to the mission and objectives of their organization. Two of the 46 survey participants indicated that they were uncomfortable with ranking forest benefits since they believe all forest benefits are equally important to healthy and resilient forests. Among those who ranked their most important ecosystem service benefits, general forest health and resilience were listed by 12 respondents, water quality by 9 respondents, recreation by 4, and fire protection, forest products, and biodiversity by 3 (Figure 3). Some of the forest benefits that were not listed most frequently as the highest priority benefit, but were listed frequently at lower rankings, included water supply, community, infrastructure, landscape beauty, and climate.

For our question asking which ecosystem services are at highest risk from disturbances that would be most harmful to the mission and objectives of their organization, general loss of forest was listed by 12 respondents, loss of property was indicated by 8 respondents, and sedimentation by 6 respondents. Loss of water quality, communities and social connections, and biodiversity each received 3 responses (Figure 4). Again, two survey participants declined to rank risks from disturbance since any disturbance could cause equally harmful devastation to the health of forest benefits. Risks that were frequently mentioned at lower than highest priority include loss of recreation opportunities, landscape beauty, stored carbon, and forest products.

Lastly, responses to the question pertaining to the biggest threat to existing forest benefits were wildfire by 34 respondents, shifting precipitation patterns by 3 respondents, and temperature alterations by 2 respondents (Figure 5)

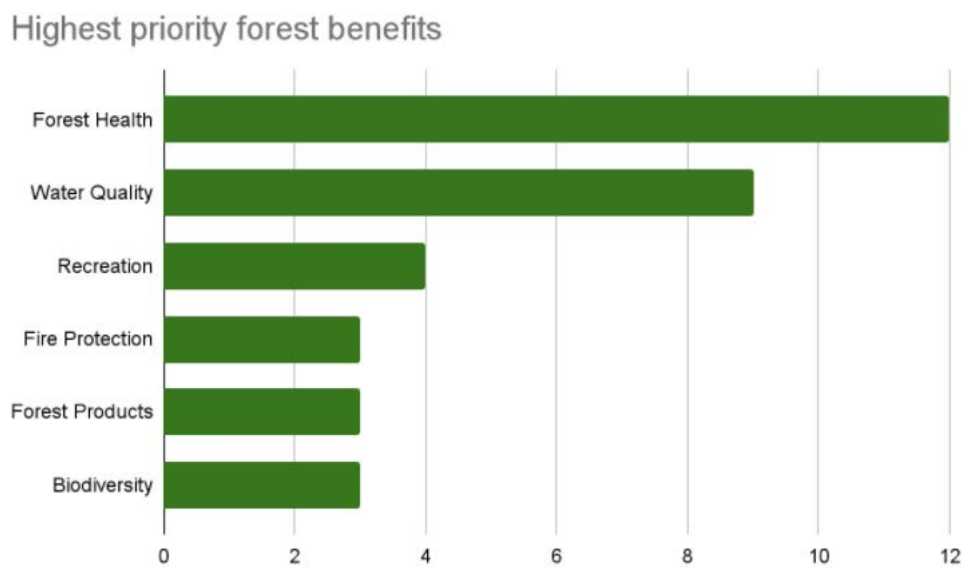


Figure 3. Bar graph showing the top six forest benefits that survey participants (n = 44) ranked as their highest priority forest benefits.

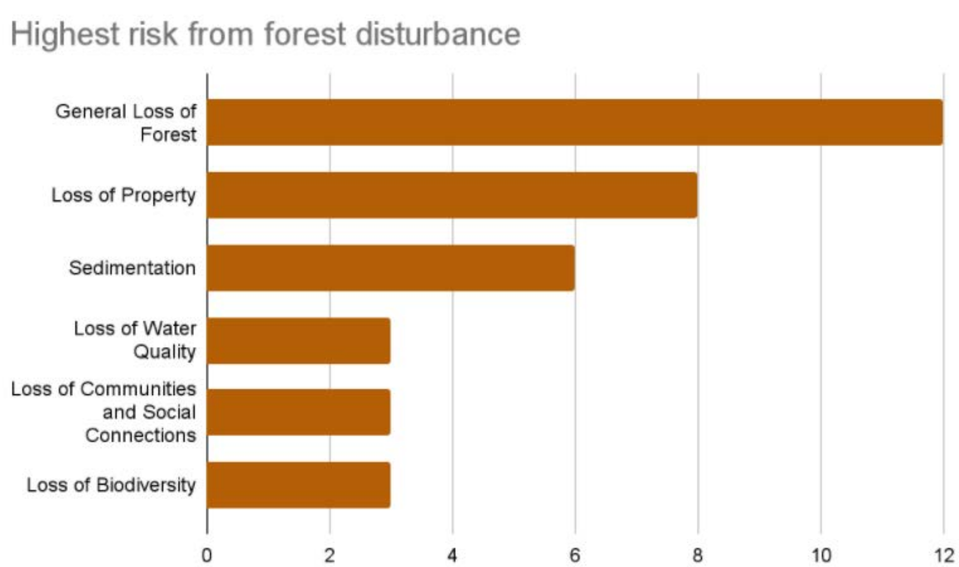


Figure 4. Bar graph showing the top six risks that survey participants (n = 44) ranked as the greatest risk from forest disturbances to ecosystem services.

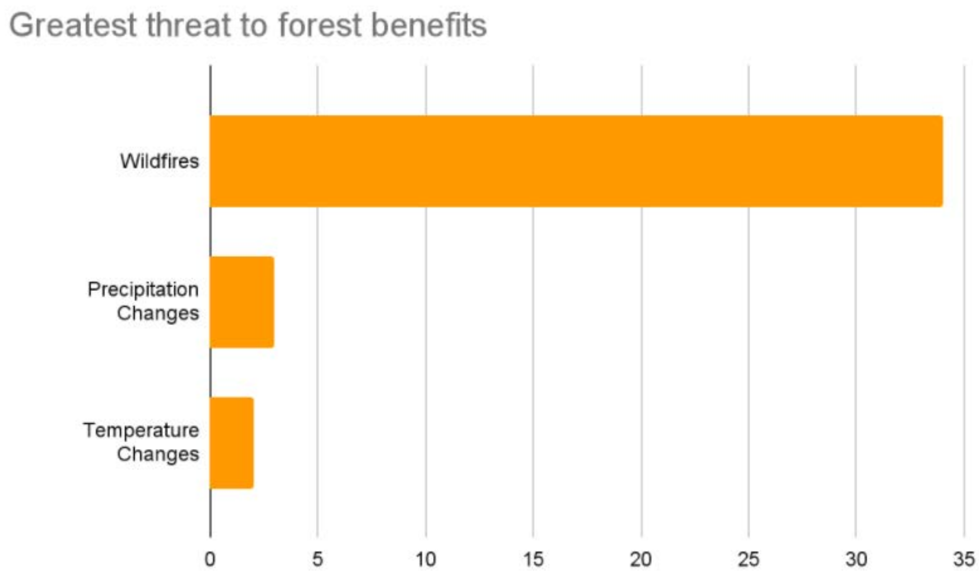


Figure 5. Bar graph showing the top threats to forest benefits identified by survey participants (n = 45).

Ultimately, our survey results were intended to help our team determine which ecosystem services were of most importance to consider for further analysis. From our results and conversations with Blue Forest, we identified ecosystem services that were of relatively high importance among stakeholders: habitat quality, water yield, sedimentation, and recreation.

4.1.2 Participatory Mapping & Semi-Structured Interview Results

Maptionnaire and semi-structured interviews proved to be fruitful in determining specific regions of importance to specific stakeholder interests. A number of stakeholders that represented county- or region-specific organizations unsurprisingly highlighted regions most pertinent to their organizations' areas of geographical interest or ecosystem services related to their organizational missions. A summary of the types of organizations represented by the interview participants is in the figure below, with nonprofit organizations representing the largest group of respondents (Figure 6). Figure 6 also shows the locations of important organization infrastructure mapped by the participants. Screenshots of examples of participants entering participatory mapping data are shown in Figure 7.

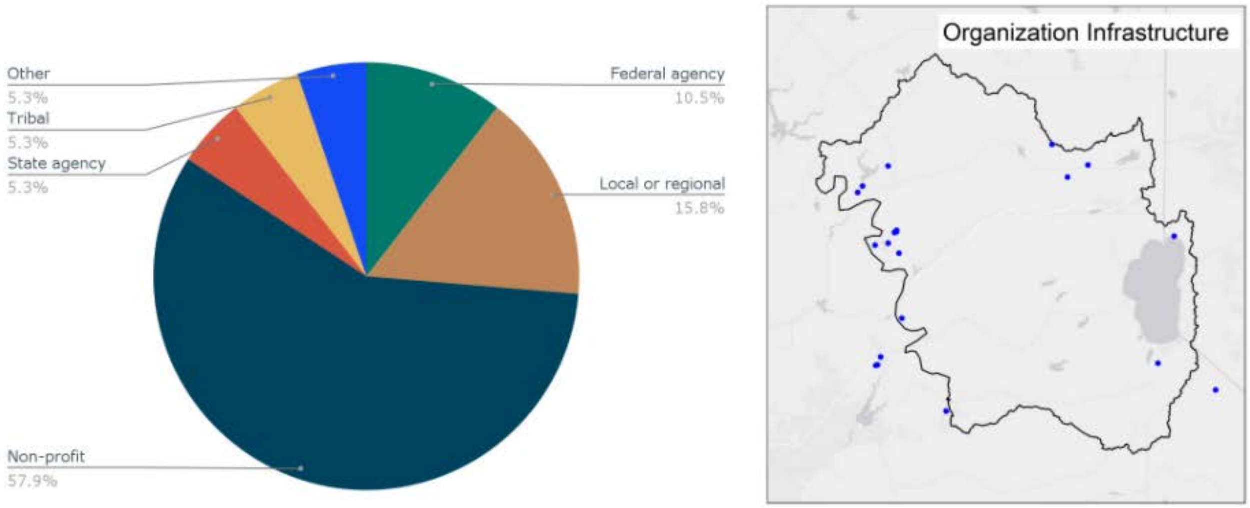


Figure 6. Percentage breakdown of interview participants' organization type and the locations (blue points) of the important organization infrastructure that they mapped.

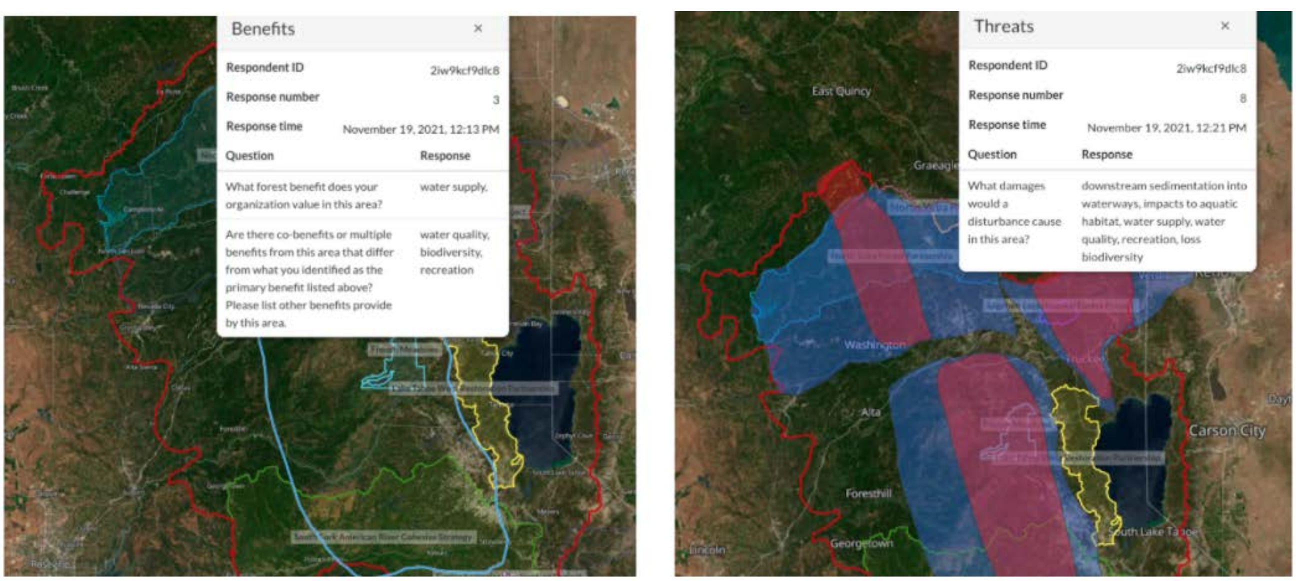


Figure 7. An example of benefits polygon and description from a participant (left). An example of a threat response polygon in red with a description from a participant overlaid on top of regions highlighted by benefits in blue (right).

From separating and stacking individual benefits, we created a heatmap that illustrates spatial areas where interview participants identified the greatest number of benefits, threats, adverse impacts, or priority management areas. While interview participants identified areas of interest throughout the Sierra region, we clipped our analysis to the greater TCSI region to align with the geographic objectives of our study. Heatmaps of areas of interest are shown in Figure 8. Our color scale ranges from either gray (count of 1) to yellow (count of 40) or purple (count of 1) to yellow (count of 25), with yellow representing areas with the greatest concentration of a given field.

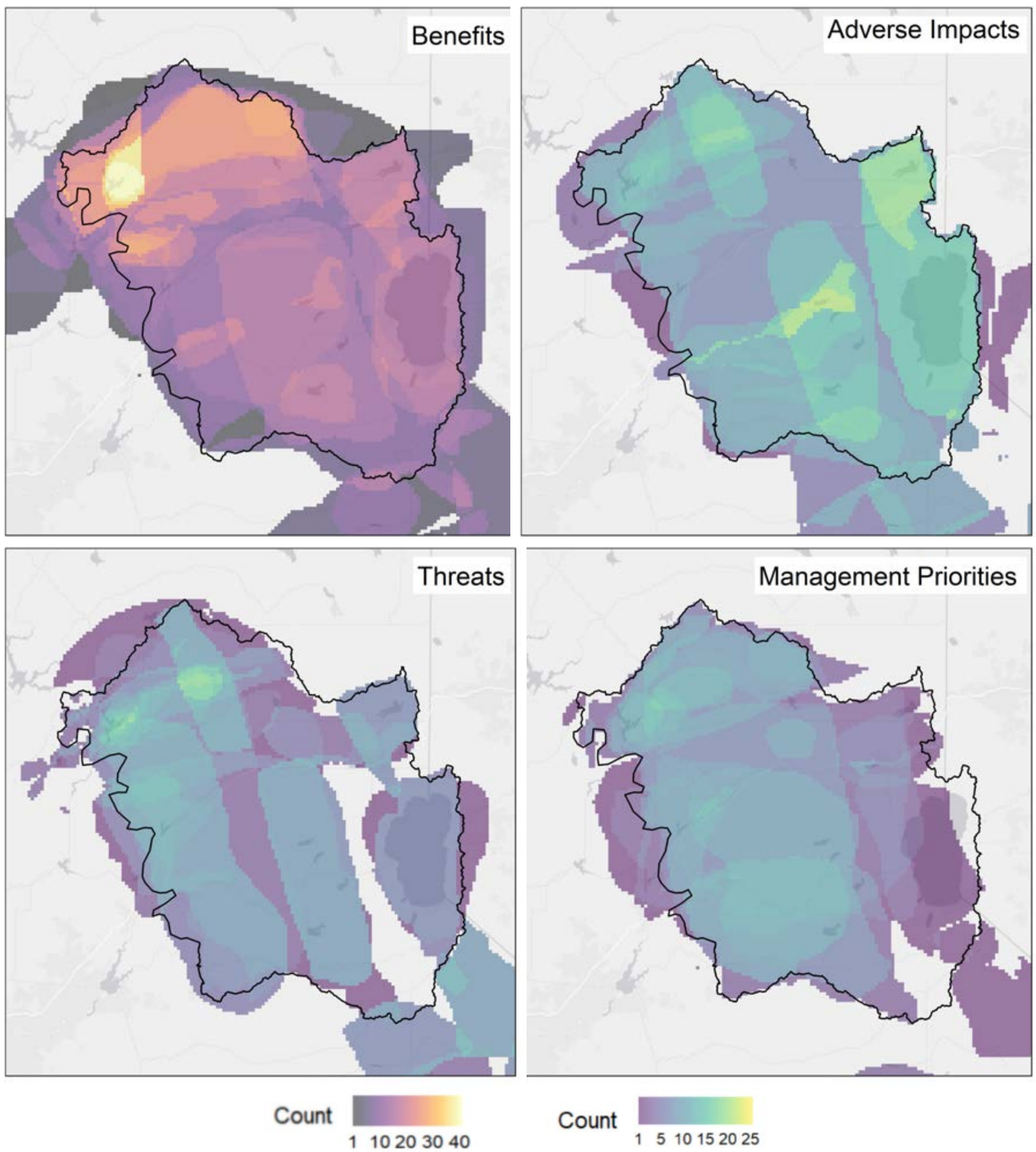


Figure 8. Heatmap of benefits, adverse impacts, threats, and management priorities from 19 survey participants' participatory mapping data. The count color ramp ranges from gray (1 count) to yellow (40 counts) for benefits, and from purple (1 count) to yellow (25 counts) for adverse impacts, threats, and management priorities.

Some of the most frequently mapped forest benefits include recreation, water quality, water supply, biodiversity, and local community and social connections. While these benefits were mapped most frequently, it does not necessarily mean that these benefits also cover the greatest spatial area. For adverse impacts, some of the most frequently mapped include sedimentation, water quality and quantity impacts, loss of biodiversity, and loss of recreation opportunities. Similarly, damages to biodiversity, local community, water supply, quality, recreation, and increased sedimentation represent the most frequently mapped threats. Water quantity and quality management and wildfire management were among the most frequently mentioned management priorities. Benefits can be broken down beyond the aggregate map shown in Figure 8. Six of the most frequently mapped benefits are shown explicitly in the maps of Figure 9.

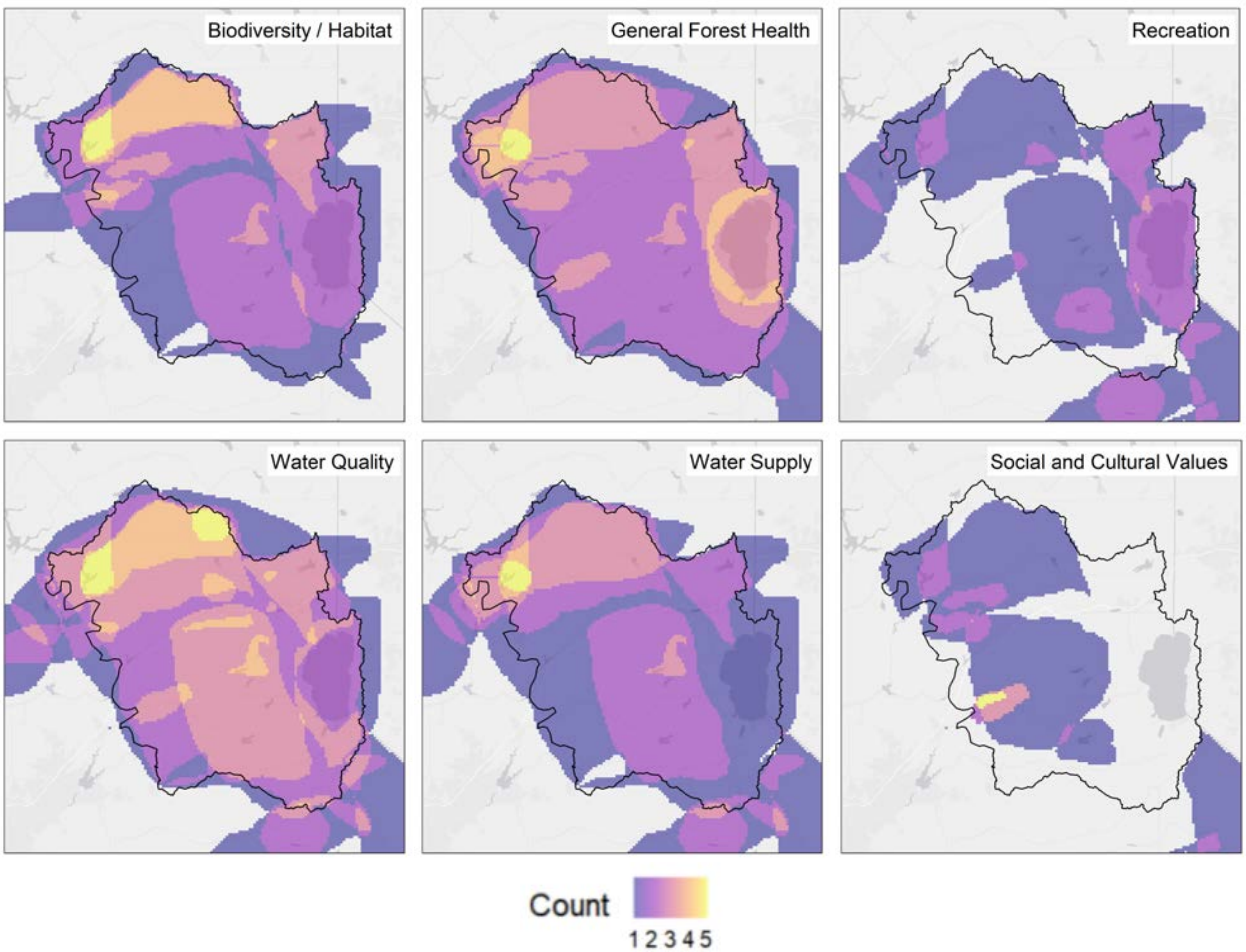


Figure 9. Heat map of frequent benefits from 19 survey participants' participatory mapping data. The count color ramp ranges from purple (1 count) to yellow (5 counts).

The yellow hotspot in the northwestern portion of the maps represents New Bullards Bar Reservoir. At the base of the reservoir is New Bullards Bar Dam, constructed by the Yuba Water Agency in 1969. The dam provides water for the Colgate Powerplant, while the reservoir is a popular recreation spot for the region (Northern California Water Association, n.d.).

The benefits mapped can also be categorized by organization type. Since the majority of organizations (58%) represented in our interview were nonprofits, it is helpful to see benefits broken out by organization type as shown in Figure 10.

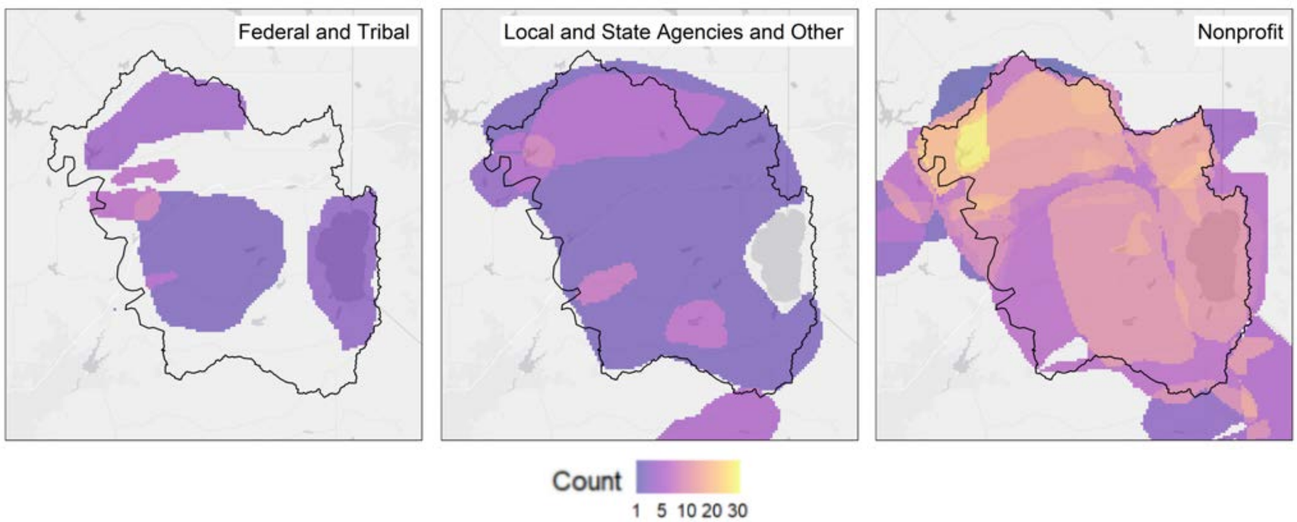


Figure 10. Heat map of benefits mapped by organization type from 19 survey participants' participatory mapping data. The color ramp ranges from purple (1 count) to yellow (30 counts).

4.2 Modeling Results

4.2.1 Annual Water Yield Results

Water yield follows consistent spatial trends across all years and scenarios. It is highest in regions of the TCSI that include the western portion of the Sierra Nevada range. Additionally, water yield is generally higher in the northern and central portions of the TCSI region and lower in the southern region (Figure 11). These spatial trends are also maintained in the runs that were generated from a land cover layer with a single land cover type (Appendix C, Figure C1.3), but the magnitude of per-pixel water yield differs for different vegetation types. Noticeably, there are more bare patches (no data values) in scenario 6 than in scenario 1, indicating that more forest transitions to barren, urban, or non-forest land cover in the LANDIS data from TNC for scenario 6 than for scenario 1 (Appendix C, Figure C1.1 & Figure C1.2). This is associated with the higher rate of forest treatment in scenario 6. Additional results from 2040, 2060, and single land cover runs are located in Appendix C.

At the subwatershed level, the subwatershed which contributes the most to total water yield is the Rubicon River watershed across all years and scenarios, though the actual amount (in m^3 of water per year) varies. In 2020, the Rubicon River watershed was modeled to yield just over 556 million m^3 of water (Appendix C, Table C1.1). In our 2060 scenario 1 high run, Rubicon River yielded almost 625 million m^3, and just over 624 million m^3 in 2060 scenario 6 high (Appendix C, Table C1.4 & Table C1.5). The order of highest- to lowest-yielding subwatersheds differs between 2020 and future results, but is consistent between scenario 1 and 6 in 2040 and 2060. Additionally, the pattern across scenarios is consistent for each watershed: 2060 scenario 1 high has the highest total water yield, followed by 2060 scenario 6 high, with 2020 having the lowest total water yield. Upper South Yuba watershed and Lower North Yuba Watershed have the highest mean water yield per pixel (mm/900 m^2) across all years and scenarios, despite never being the highest-yielding watersheds in terms of total water yield (Appendix C, Tables C1.1-C1.5). Tabulated values of total and mean annual water yield by subwatershed are in Appendix C.

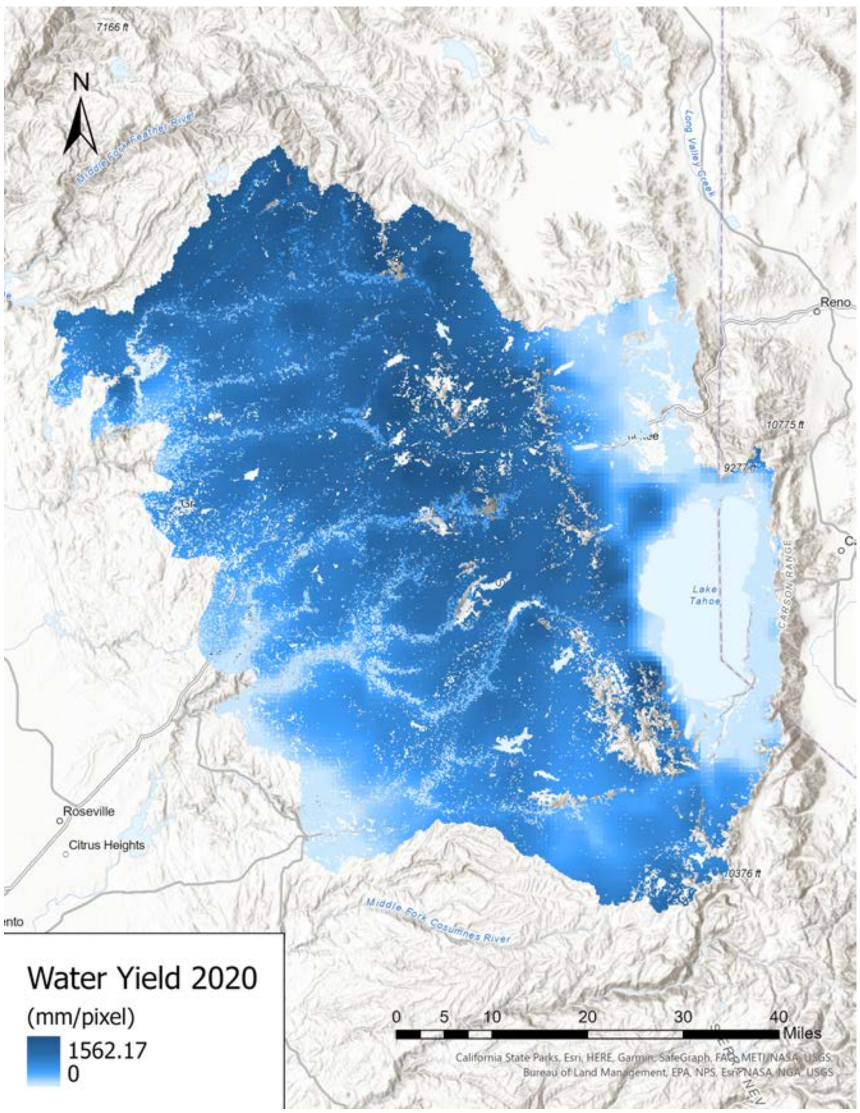


Figure 11. Results from the Water Yield model in 2020, where darker blue represents regions of higher annual water yield (mm/900 m^2 pixel).

4.2.2 Sediment Delivery Ratio Results

From our sedimentation analysis, we determined the difference between current (2020) and projected sediment export at two scales: the HUC 10 (Appendix C, Table C2.1) watershed level across the whole region and the level of the watersheds associated with the 20 largest dams in the TCSI (Appendix C, Table C2.2).

Sediment export per watershed in 2020 was subtracted from sediment export per watershed in each projected scenario. Consequently, darker brown represents watersheds that are projected to export more sediment into local streams in the future compared to current conditions, while lighter brown represents watersheds that are projected to export less sediment into local streams compared to current conditions (Appendix C, Figures C2.1 & C2.2). Information on the watersheds included in this analysis, such as watershed name, area, and amount of exported sediment can be found in Appendix C.

Overall, the watersheds with the highest sediment export in the future compared to current conditions are found in the northern and central regions of the TCSI (Appendix C, Figure C2.1). Additionally, sediment export is expected to increase in the future for all watersheds (Appendix C, Tables C2.3-C2.6). However, there are differences between each projection.

1. HUC 10 Watersheds

For the analysis of all watersheds in the study area at the HUC 10 level, major sediment export differences range from 118,999 tons per watershed to 3,583,637 tons per watershed in all projections (Appendix C, Tables C2.3 & C2.4). However, when ranking watersheds by sediment differences, the order of the ranked watersheds is consistent. The Lower South Fork American River watershed consistently has the lowest sediment export, while the Upper North Fork American River watershed consistently has the most. A similar trend arises when analyzing differences between the scenarios. Scenario 1 has consistently higher sediment export when compared to scenario 6 across all analyzed watersheds. However, the differences between years do not follow as consistent a pattern as the differences between scenarios. For example, the mean sediment export for the Lower South Fork American River is lower in 2040 than in 2060 (121,150.25 tons vs. 121,778.5 tons, respectively). Meanwhile, the mean sediment export for the Upper North Fork American River watershed is higher in 2040 than in 2060 (3,476,353 tons vs. 3,414,500 tons, respectively).

2. Dam Watersheds

When considering only the HUC 12 watersheds associated with the 20 largest dams (by reservoir capacity) in the TCSI, the range of the differences in sediment export is 14,694 to 9,490,783 tons per watershed. Similar to the HUC 10 analysis, the ranking of sediment export differences remained consistent among scenarios and years. The dam with the lowest difference between current and projected sediment export is French Lake Dam, while the dam with the highest difference is the New Bullards Bar Dam (Appendix C, Tables C2.5 & C2.6).

4.2.3 Recreation Analysis

1. Impacts of Climate and Fire on Recreation: Literature Review

Recreation choices are impacted by changing conditions, which include changes in travel costs, disposable income, leisure time, and physical conditions such as temperature, drought, and wildfires. Our study will focus on changes in physical conditions. With climate change, peak visitation to National Parks is projected to occur earlier in the year. Temperature was found to be strongly associated with visitation rates at 83% of National Parks. Therefore, visitation is projected to increase at national parks with warming, until temperatures reach over 25 degrees Celsius and become too hot for visitors (Fisichelli et al., 2015).

While temperature tends to have a positive impact on warm-weather recreation activities up to a certain point, wildfires have varying impacts on recreation (Fisichelli et al., 2015; Sánchez et al., 2021; Bawa, 2016). A literature review on recreation impacts from wildfires in western North America conducted by Bawa (2016) found that although the majority of studies found wildfires decrease the value of a recreation visit, some studies found that wildfires can cause a spike in visitation. For example, some visitors, especially in California, may associate the positive impacts of forest thinning with a wildfire and may want to see if there are any new species impacts, such as a wildflower bloom (Bawa, 2016). These changes in visitation after a wildfire may also be short-lived, and the enjoyment recreationists receive from a site may not be impacted by a burned landscape (White et al., 2021). Other studies consider the popularity of certain destinations and limits regarding securing campground permits or reservations and how this might incentivize visitors to travel to areas of recent wildfire activity (Gellman et al., 2022). Overall, it can be challenging to generalize the impacts of a wildfire, because each disturbance is unique and community members may have different reactions to wildfires in their region (Bawa, 2016).

A major impact from active wildfires is the smoke they produce. Almost 400,000 campground visitor days are impacted by smoke each year in the western United States (Gellman et al., 2022). This impact from smoke corresponds to a welfare loss of about $4.8 million per year from canceled camping trips and smoke-related illness impacts. For campgrounds within 20 km of an active fire, occupancy rates drop by about 6.4 percentage points (Gellman et al., 2022). In Eldorado National Forest in 2017, about 40% of people who lodged overnight on their trip stayed at a campground (NVUM, 2022). Wildfires and smoke impact the recreation choices that people make. During the dual COVID-19 and western U.S. wildfire public health events of 2020, mobile cell phone data indicated that people chose to visit national and state parks that were further from wildfires and smoke impacts and that they spent less time at these parks while wildfires were active. However, since smoke and COVID-19 both lead to respiratory impacts, people may have been more avoidant of smoke than usual during the pandemic (Yang et al., 2021). The complicated relationships between fire and recreation motivated us to measure the observable impacts on visitation rates during an active fire using Flickr data and calculate monetary losses from existing NVUM visitation data. These figures are likely to underestimate total economic losses. Notably, they do not account for shifting visitation rates as tourists and recreationists alter plans to avoid smoke and active fires. However, they provide a lower bound of the total impact, which is expected to be larger than our estimates.

2. Regression Analysis

The final regression estimating the effect of the King Fire on recreation activity had 1,744,320 observations for 14,536 FID points in the TCSI region. The model in column 1 shows the regression without accounting for fixed effects. This regression shows the effect of various amenities on recreation activity. Each coefficient was statistically significant. In general, recreation opportunities had a positive effect on PUDs, while greater distance to recreation opportunities was associated with a decline in PUDs. These effects persisted even after accounting for month and year fixed effects in column 2. Column 3 controls for FID fixed effects, which removes the influence of time-invariant, location-specific unobserved factors. We calculated the impact on visitation while the King Fire was active to be -0.011 ($p < 0.01$). When dividing this coefficient by the PUD mean (0.035), we calculate a drop in visitation of 31.4% within the 30 km buffered region of the King Fire (Table 2).

From the regression using lead and lag months, there was no consistent evidence for time-varying effects of the King Fire on visitation rates after the fire was extinguished. From our regression modeling we could conclude that while the King Fire was actively burning, visitation rates within the 30 km buffered region around King Fire decreased by our calculated percentage, 31.4%. However, the impact of the King Fire on visitation lasted only while the fire was actively burning, with no discernible effects after it was extinguished.

Table 2. Contemporaneous regression results after controlling for fixed effects of variables. Column 1 represents the regression run without any fixed effects, column 2 represents the regression run with month and year fixed effects, and column 3 represents the regression run with month, year, and individual FID point fixed effects.

	PUD (1)	PUD (2)	PUD (3)
Intercept	0.034***		
	(0.002)		
Wilderness	-0.005***	-0.005***	
	(0.002)	(0.002)	
Tahoe	0.016***	0.016***	
	(0.004)	(0.004)	
Hiking	0.007	0.007	
	(0.007)	(0.007)	
Ski	0.027***	0.027***	
	(0.004)	(0.004)	
Highways	0.053***	0.053***	
	(0.017)	(0.017)	
Lakes	0.004	0.004	
	(0.003)	(0.003)	
Towns	0.046***	0.046***	
	(0.005)	(0.005)	
Dist. to rec. opp.	-0.003***	-0.003***	
	(0.001)	(0.001)	
$(\text{Dist. to rec. opp.})^2$	0.000***	0.000***	
	(0.000)	(0.000)	
King Fire active	-0.019***	-0.011***	-0.011***
	(0.001)	(0.002)	(0.001)
N	1,744,320	1,744,320	1,744,320
FID FE	No	No	Yes
Month FE	No	Yes	Yes
Year FE	No	Yes	Yes
Mean PUD	0.035	0.035	0.035

Notes: Standard errors clustered at the FID level.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

4.2.4 General Forest Health (Biodiversity)

The ten most prevalent forest conversions were analyzed based on the number of cells or pixels, converted to acres, that changed from one forest species to another. As previously stated, there were over 100 forest type conversions for each year and scenario. Therefore, only the top 10 most significant changes were addressed for each year and scenario. Maps and tables of results from 2040 scenario 1 and 6 as well as 2060 scenario 1 can be found in Appendix D.

Overall, forest type conversions were similar within the years (high and low restoration) but slightly different between the scenarios (1 and 6). Forest conversions involving Douglas fir were the most abundant in both scenario 1 and 6 (Figure 13). In scenario 1, the least abundant forest conversion was Red fir to Sierra mixed conifer while in scenario 6, the least abundant forest conversion was White fir to Jeffrey pine. In the various scenarios, there is an overall net loss of mixed forest habitat and a net gain in single species stands. Mixed forest stands in general had negative percent change values or net loss of habitat while single species such as Douglas fir and Ponderosa pine had positive percent changes or an increase in habitat. Mixed hardwood conifer experienced more loss in scenario 1 than 6, while Sierra mixed conifer and Sierra high elevation mixed conifer experienced more loss in scenario 6 than in scenario 1 (Table 4).

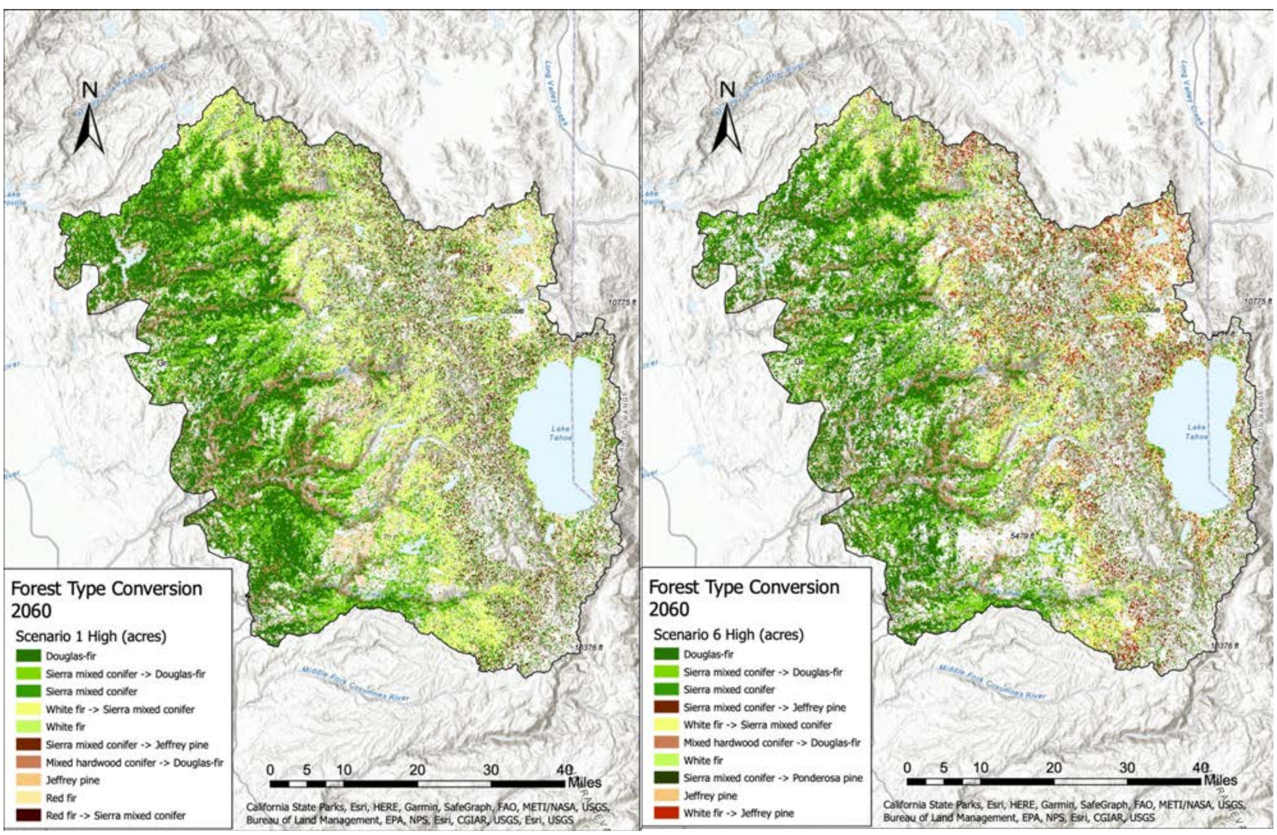


Figure 13. Top ten most significant forest conversions by acreage for 2060 scenario 1 and 6 listed from the greatest change (top) to least greatest change (bottom). Legend symbology is based on the different types of forest conversions. Symbology is consistent throughout the years and scenarios.

4.2 Modeling Results

On the landscape as a whole in 2060, Douglas fir is projected to have the greatest overall presence in the landscape, gaining 384,545.79 acres in scenario 1 (high) and 271,586.32 acres in scenario 6 (high). In total, Douglas fir will occupy approximately 829,882.66 acres (scenario 1 high) and 691,143.22 acres (scenario 6 high) of the TCSI landscape in 2060 (Table 4).

On the other hand, 203,477.57 acres of white fir habitat will be lost in scenario 1 2060 (high), which is the largest net change from 2020 to 2060 out of the 14 habitat types. In scenario 6 (high), 207,584.75 acres of white fir will be lost, making it the second greatest net change from 2020 to 2060 out of the 14 habitat types. However, white fir will still be at least the fifth most abundant species in the landscape, totaling 137,474.46 acres in scenario 1 (high) and 87,900.07 acres in scenario 6 (high) in 2060 (Table 4).

Another notable forest type conversion is the drastic increase of lodgepole pine habitat, gaining 12,401.60 acres in scenario 1 (high) and 22,409.35 acres in scenario 6 (high) in 2060. This brings lodgepole pine habitat to a total of 12,761.88 acres in scenario 1 (high) and 22,769.63 acres in scenario 6 (high) resulting in a 3,442.22% and 6,220.00% increase in lodgepole pine habitat in 2060, respectively.

Table 4. Net change, total area, and percent change of each forest type for scenario 1 (top) and 6 (bottom) in 2060. Negative net change values equate to loss while positive values are gain.

2060 Scenario 1 High

Forest Type	Net Change 2020-2060 (acres)	Total Area 2060 (acres)	Percent Change 2020-2060
Aspen	344.27	344.27	Increase from 0
Chapparal	32.02	40.03	400.00%
Douglas-fir	384,545.79	829,882.66	86.35%
Jeffrey pine	107,066.91	204,366.26	110.04%
Juniper	7,021.44	11,873.19	144.72%
Lodgepole pine	12,401.60	12,761.88	3442.22%
Mixed hardwood conifer	-97,787.73	14,715.40	-86.92%
Montane hardwood	-15,956.36	13,786.68	-53.65%
Montane riparian	-96.07	232.18	-29.27%
Ponderosa pine	33,025.58	112,735.30	41.43%
Red fir	-31,464.37	95,570.01	-24.77%
Sierra high elevation mixed conifer	-32,281.00	48,965.92	-39.73%
Sierra mixed conifer	-163,374.52	480,844.37	-25.36%
White fir	-203,477.57	137,474.46	-59.68%

2060 Scenario 6 High

Forest Type	Net Change 2020-2060 (acres)	Total Area 2060 (acres)	Percent Change 2020-2060
Aspen	1,729.34	1,729.34	Increase from 0
Chapparal	40.03	40.03	Increase from 0
Douglas-fir	271,586.32	691,143.22	64.73%
Jeffrey pine	189,018.38	273,924.13	222.62%
Juniper	2,409.87	6,965.39	52.90%
Lodgepole pine	22,409.35	22,769.63	6220.00%
Mixed hardwood conifer	-82,503.89	28,229.86	-74.51%
Montane hardwood	11,729.08	40,887.66	40.23%
Montane riparian	624.48	936.73	200.00%
Ponderosa pine	107,851.52	181,620.65	146.20%
Red fir	-52,536.68	60,895.16	-46.32%
Sierra high elevation mixed conifer	-37,821.29	40,463.33	-48.31%
Sierra mixed conifer	-226,951.75	358,149.35	-38.79%
White fir	-207,584.75	87,900.07	-70.25%

4.2.5 Interview and Modeling Results Overlay

By overlaying modeled water yield with stakeholder-identified water supply benefits in the TCSI, we generally see congruence, with some discrepancies. Stakeholders most highly recognize water supply in the northwest portion of the region, followed by the rest of the north and the center portion of the TCSI. The north and center of the TCSI tend to have the highest per-pixel water yield, but interestingly the northwest is relatively low in terms of per-pixel water yield from the land. While stakeholders recognize the importance of the north and central regions for water yield, they also seem to overestimate the contribution of the northwest region. However, this area of highest stakeholder interest in the northwest aligns with New Bullards Bar Reservoir, a major source of water and hydropower in the region. In general, the 20 major dams align with no data points in the water yield layer, which in this case represent water bodies, likely the reservoirs associated with each dam. Many, but not all, of these dams are encapsulated in the areas of high stakeholder interest in the north and center of the TCSI (Figure 14).

4.2 Modeling Results

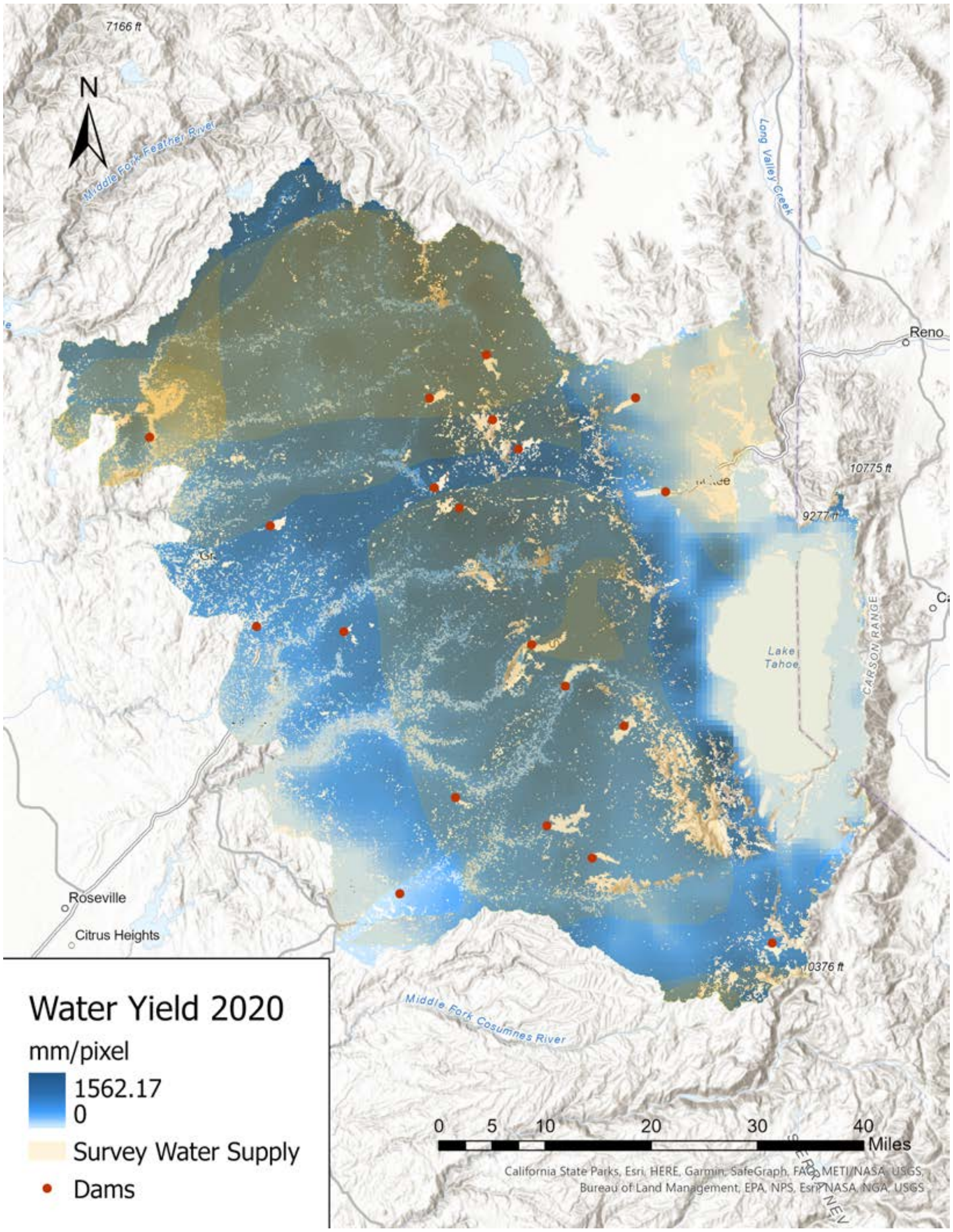


Figure 14. Overlaid results from water yield model (blue) and stakeholder-identified water supply through interviews (peach), with locations of 20 largest dams (red dots) in the region added.

5.0 DISCUSSION

There is general agreement between the locations of important forest benefits identified in our stakeholder analysis and in our modeling efforts. Additionally, the water services modeled (water yield and sedimentation) broadly overlap in terms of focal locations of importance for restoration. In particular, the north and center of the TCSI are potentially impactful locations for a future FRB that centers water benefits. These areas are also widely recognized by stakeholders for their contributions to water supply. The forest benefits valued by stakeholders and the ecosystem services modeled here will all be impacted by climate change as wildfire and changes in precipitation and temperature increase in frequency and severity. Notably, active wildfires decrease visitation to the region, which has potentially major implications for the TCSI region, which is a popular destination for tourism and recreation. In application, particular opportunities to advance restoration can be achieved by selecting ecosystem service priorities, such as specific forest species or sedimentation thresholds, that stakeholders value and are willing to engage with as collaborators for future FRBs.

5.1 Stakeholder Analysis Discussion

5.1.1 Survey Discussion

Some challenges we faced in our survey design and analysis include determining the interests and demand for ecosystem services across a landscape, particularly when considering the interactions and co-benefits from ecosystem services. We also had unequal representation in the type of organization interviewed. For example, access to culturally or spiritually important places, as well as strong local economies, were two themes that were frequent in a few responses, but not in a way that led these themes to have the highest number of responses. On the other hand, general forest health and resilience was very highly ranked, possibly due to our strong response rate from environmental nonprofit organizations, which represented 34% of our respondents.

We believe that the ignition of the Caldor Fire had a significant impact on the response rate from the forest collaborative SOFAR. Furthermore, conducting the survey during wildfire season made the threat of wildfire very salient and may have contributed to its disproportionately high ranking as the greatest threat to forest benefits. Given time constraints of the project, and concern about the approaching fire season impacting survey response rates, we did not identify a participatory mapping tool that could be combined with our SurveyMonkey survey. After we distributed the survey, we identified the Maptionnaire Community Engagement Platform for use in our semi-structured interviews. While it could have been informative to collect spatial data from our survey participants, we felt that using the tool only for semi-structured interviews provided a way for team members to coach participants on how to use the mapping software.

5.1.2 Participatory Mapping and Semi-Structured Interview Discussion

The combination of semi-structured interviews with the participatory mapping questionnaire proved to be an effective technique to identify regions of interest to respondents and their particular interest in each mapped polygon. Facilitating interviews proved to be a challenging task, but was refined after the first few interviews. Participants responded well to the use of the mapping tool. We did not secure a subscription to Maptionnaire until late August 2021 and had already distributed our survey through the points of contact in the forest collaboratives in the region. Had we identified Maptionnaire as a survey tool earlier, we would have been interested in distributing our survey through Maptionnaire instead of through SurveyMonkey to capture larger volumes of spatial data. In addition to the spatial data we analyzed from Maptionairre in the results section, we discuss some broader themes from the semi-structured interviews we conducted in tangent with the mapping exercise.

Most interviewees connected their definitions of forest health and resilience to forests characterized by low density and a mosaic of tree species, to the provision of ecosystem services needed by the community, and to the ability of the forest to bounce back from disturbances such as wildfire. One interviewee summarized this as building a culture of living with fire. The provision of water quality and water supply was mentioned frequently; whereas, the provision of safe and revenue-generating recreation opportunities was mentioned less frequently. One interviewee connected general forest health and resilience to the resilience of communities and the importance of creating access for tribal communities.

While specific benefits mentioned by the interviewees are captured by their survey responses and mapped benefits, interviewees frequently mentioned that overall forest health and resilience is the most important benefit because overall forest health will impact the quality and provision of all other ecosystem services. The connection of healthy forests to tourism and recreation was also frequently referenced. One interviewee astutely acknowledged that forest restoration is much cheaper than the economic impacts of a wildfire. Some organizations are intrigued by using an economic component to assess benefits but are hesitant to tie economic impact to specific projects. For now, the economic component tends to be connected to tourism and recreation impacts. Biomass for electricity was also mentioned infrequently.

Organizations interviewed did not typically have metrics to track their own forest benefits, but several work with collaborators to track benefits on a larger scale. The U.S. Forest Service is frequently the partner for tracking benefits. Two organizations mentioned the importance of integrative projects and stacked benefits on the landscape for attracting collaboration from partners, and another organization noted that collaboration for projects may be a metric in its own right. Other potential metrics mentioned include fire insurance and carbon storage.

From our survey and mapping, sedimentation was frequently listed as an adverse impact. From the interviews, we learned that sedimentation can be especially impactful because it can cause detrimental community health impacts. It was frequently mentioned that waterways are important for communities and should be protected to increase community enjoyment of rivers. One interviewee mentioned that sedimentation is the largest source of pollution for California rivers and creates challenges for aquatic species, drinking water, and water treatment. Air quality was also mentioned as another adverse public health impact. Summer can be a particularly challenging time as there are more visitors and higher risk of adverse impacts. The first flush after a big fire in the late fall or early winter can also be dangerous. With the lengthening wildfire season, these impacts can occur at any time, which can be challenging for tourism, and losses extend beyond physical damages to cultural and psychological impacts.

As shown in the survey and mapping, wildfire is a major threat to this region. However, some nuances were captured from our conversations. Wildfire risk is closely related to drought and climate change. Changes in temperature increase bark beetles' overwinter survival rates, which can interact with increased drought stress to make trees more susceptible to fire. Additionally, wildfires can lead to other threats such as erosion and decreased safety of recreation opportunities. Reactive management and risk aversion to prescribed burns can worsen the threat of severe wildfires in this region, exacerbating the issue. Most organizations mentioned that communities and collaboration are key to identifying management priorities within the region.

5.2 Modeling Discussion

5.2.1 InVEST Discussion

InVEST can provide helpful estimates of the quantities and spatial distributions of many ecosystem services, although there are some downsides to solely relying on the software.

For example, Podolak et al. (2017) found that the model suite was not extensive enough to capture all ecosystem services that stakeholders mentioned and prioritized. Therefore, they were limited when using the models to find synergies and trade-offs among objectives. Since stakeholders in the TCSI are incredibly diverse, the same limitations apply to this analysis. Another limitation is InVEST's heavy reliance on data. Although the software can work with limited data, the outputs of the models are less reliable if the inputs are not representative of the full scope of a given region of interest.

5.2.2 Annual Water Yield Model

The trend in spatial distribution of water yield throughout the TCSI is similar across time and restoration scenarios. Mountainous portions of the study area typically contribute more water annually than those at lower elevation. This result is unsurprising, as steeper slopes and resilient vegetation are known to contribute to a robust and stable water balance (Wagenbrenner et al., 2021).

The lack of clear differences between future years and scenarios is not an expected result of the water yield model, as scenarios 1 and 6 represent extremes along the spectrum of forest restoration per year, and our selection of the high and low change replicates for each scenario and year should ensure significant differences. However, this result is likely driven by two factors. First, the annual water yield model is largely controlled by precipitation data, as evidenced by the continued similarity between model runs using a single vegetation type for the land cover layer. Due to the long time scales and inherent uncertainty of climate modeling, all future scenarios were run with the same precipitation data representing an average of precipitation over the time period between 2035 and 2064. More specific climate projections would likely have produced different results.

Second, much of the change between years and scenarios includes change from forested to non-forested land cover, i.e. early successional vegetation types like meadows or shrub. This is consistent with our understanding of the impact of forest restoration, particularly restoration driven by thinning and prescribed burning. However, changes to meadow and shrub that were identified in the LANDIS-II modeling that produced our land cover layers became no data points alongside barren, urban, and lacustrine patches. We expect that a different analysis including time to convert these patches to individual urban, barren, lacustrine, or non-forest patches would have impacted the pattern and overall water yield in our scenarios. Pixel-scale (900 square meter) differences within this larger pattern do exist and represent locations where vegetation type switched between one of the five classes used in our InVEST analysis (conifer, hardwood, mixed, shrub, or non-forest); however, these differences are rare as the majority of changes are between species within a single class (see Biodiversity results and discussion).

At the subwatershed level, water yield is higher in the future than under current conditions. This is likely driven by the updated precipitation data, which again controls much of the water yield model. Based on expected increases in water yield due to the thinning of forests during restoration (Wagenbrenner et al., 2021), we would expect water yield to be higher across subwatersheds in scenario 6, but our results show higher water yield in scenario 1. This is possibly due to the increased number of no data cells in scenario 6 compared to scenario 1, as this decreases the number of cells contributing water yield to each subwatershed. Future modeling should modify the land cover data to include vegetation where the forest has transitioned to meadow or shrub, in order to more robustly assess the impact of restoration and early successional vegetation types on water yield.

5.2.3 Sediment Delivery Ratio Model

Overall, sedimentation export increased in all year and scenario projections. This is to be expected because all of the projections are modeled under a hot and dry version of MIROC5 under RCP 8.5 climate scenarios. Since this scenario represents a worst-case (business as usual) scenario (Riahi et al., 2011), temperatures are extreme, leading to larger, more severe wildfires (Williams et al., 2019), even with restoration.

The highest increase in sediment export is most evident in the northern and central regions of the TCSI. This is primarily due to the terrain of these areas. As stated in the Annual Water Yield section, these regions contain relatively high amounts of precipitation and steep slopes when compared with the rest of TCSI. The high amount of precipitation affects erosion through processes such as instantaneous impact onto surfaces, which help weather material, while the higher slopes enhance erosion of sediments into streams (Shi et al., 2012). This erosive force is counterbalanced by forests within the area, whose deep roots and canopy prevent sediment erosion (Buckley et al., 2014). However, as land cover changes (Appendix D, Figure D1), so too does sediment export and erosion.

When looking at the differences between watersheds, the Lower South Fork American River watershed consistently had the lowest amount of sediment export, while the Upper North Fork American River watershed consistently had the most. However, the Lower South Fork American watershed is one of the smallest area watersheds within TCSI, at only 37 square km. Meanwhile, the North Fork American River watershed is substantially bigger, with 287 square km within the boundaries (Appendix C, Table C2.1). When normalizing for area, the Lower South Fork American River watershed has approximately 3288.41 tons/square km of sediment export, while the North Fork American River watershed has approximately 5243.56 tons/square km. Once normalized by area, the watershed with the least difference in sediment export is the Prosser Creek-Truckee River watershed, with 1123.96 tons/square km, while the watershed with the most difference is in the Yuba River watershed, with 25184.87 tons/square km. This also follows a similar trend as the sum of sediment differences because the Yuba River watershed is located in the northern region of TCSI (i.e., steeper slopes and higher rainfall), while the Prosser Creek-Truckee River watershed is a large watershed in the eastern region (i.e. lower slopes and less rainfall).

On the dam watershed level, it is important to analyze the total amount of sediments within the watershed. This is because sedimentation impacts the amount of water that dams can hold. As streams reach the dams, their velocities become reduced and many sediments that were suspended in the stream fall out of the water column and fill dams. This can have significant impacts on dam operations in the region and be extremely expensive to remove (Palmieri et al., 2001).

In this analysis, the French Lake dam had the lowest sedimentation difference (mean = 15,929), while the New Bullards Bar Dam had the highest sedimentation difference (mean = 9,068,660). However, since the New Bullards Bar Dam is fed by multiple watersheds within the northern regions of TCSI, sediment has been a major problem that the Yuba Water Agency, the owners of the dam, have to face (Curtis et al., 2006). Although they have been conducting sediment removal projects (Association of California Watershed Agencies, 2019) in the watershed, their sediment issues will continue getting worse as time passes.

Both HUC 10 and dam watershed analyses show a similar trend when it comes to restoration scenarios. Scenario 6, which contains more restoration (e.g., thinning and prescribed burns) had consistently less sediment export than scenario 1, which contains minimal restoration. This is not surprising, as forest restoration through mechanical thinning has been shown to maintain healthy forests, which retain soil on the land.
Future modeling for sediment export should use more information than just land cover. Sediment erosion is affected by numerous factors that were not accounted for in this analysis such as the age of forests (Buckley et al., 2014) and their stand density (i.e. canopy cover) which have been shown to affect the erosion of soils (Razafindrabe et al., 2010). Additionally, accounting for all dams, rather than just the top 20 dams might provide more detailed information.

5.2.4 Recreation

From our regression analysis, we discerned a 31.4% decrease in visitation rates while the King Fire actively burned between September and October 2014 from Flickr PUD data. While we were unable to measure lasting lag effects from the King Fire on visitation rates through Flickr data, the financial loss during the fire to recreation within Eldorado National Forest could be useful to illustrate the welfare loss due to the fire. To calculate the impact of the King Fire, while actively burning, on visitation within the Eldorado National Forest, we used visitation data from 2017. In 2017, 1,202,000 people visited Eldorado National Forest to recreate across a variety of activities. NVUM data indicates that hiking/walking accounted for 18.7% of the main activity respondents indicated as their activity of choice.

5.2 Modeling Discussion

From the annual visitation data, we calculated monthly visitation using the same distribution of the most recent monthly Flickr PUD data accessed through InVEST. For example, if 18% of the total PUD were from July, then we assumed that 18% of the most recent survey of annual total visitors, or 215,342, were at Eldorado National Forest in July. Following methods outlined in Rosenberger et al. (2017) for the USDA, we estimated recreation economic value for Eldorado National Forest for the most recent visitation year. The average visit to Eldorado National Forest corresponded to an economic value of $96.85 or a total annual economic benefit of $116 million dollars. If a fire the same size as the King Fire were to occur in September and October, then we could expect to see a drop of about 55,000 visitors and an economic loss of $5.4 million dollars (Table 5). From this table, we can conclude that if the same size fire did occur in the summer when visitation rates are highest, economic losses could be nearly double.

Table 5. Economic impact to Eldorado National Forest visitors for each month, if a fire the same size of the King Fire were to occur during that month.

Month	Visitors projected from PUD	Visitors, if fire had occurred that month	Economic value of visitation loss ($)
January	144,866.45	99,336.99	4,409,528
February	101,798.05	69,804.37	3,098,587
March	93,967.43	64,434.81	2,860,234
April	62,644.95	42,956.54	1,906,823
May	46,983.71	32,217.40	1,430,117
June	199,680.78	136,923.96	6,077,998
July	215,342.02	147,663.10	6,554,703
August	93,967.43	64,434.81	2,860,234
September	140,951.14	96,652.21	4,290,351
October	35,237.79	24,163.05	1,072,588
November	39,153.09	26,847.84	1,191,764
December	27,407.17	18,793.49	834,235

In 2015, it is estimated that the Lake Tahoe Basin Management Unit and the Tahoe National Forest experienced losses in recreation services of $73 million and $36 million, respectively, from drought-caused tree mortality impacts from bark beetles and wildfires (Sánchez et al., 2021). If these losses are looked at on a per-month basis in today's dollars, then they would range between $3.5 million to $7 million, which is similar to our predicted loss of $5.4 million in recreation for Eldorado National Forest due to a fire similar to the King Fire.

Our modeling approach did not account for shifts in visitation that might occur due to an active wildfire. For example, we are unable to account for visitors that might have altered their plans to recreate in a region further from an active wildfire. Based on 2017 NVUM survey data, 55% of visitors would have been willing to visit somewhere else for the same primary recreation activity. Furthermore, 28% of those visitors would have been willing to travel 101 to 200 miles from their homes to an alternate location for their recreation. Therefore, it is likely that some recreation losses we calculated were not losses but rather transfers to other outdoor recreation areas. However, this does represent a loss to the region around Eldorado National Forest. We also know that 45% of visitors in 2017 had an overnight stay from home on their trip to Eldorado, indicating that trips to this forest included a significant cost for visitors.

5.2.5 General Forest Health (Biodiversity)

Identifying forest type conversions on the landscape can help pinpoint priority locations for forest restoration projects. By examining where and how much of a certain forest type is converted into another forest type, we are better able to understand where restoration projects should occur, particularly if one of the goals of the project is to maintain biodiverse habitats for important wildlife species. The particular forest conversions will also be important to analyze as a loss or gain in a particular forest type could be devastating or beneficial to the environment and wildlife dependent on that forest type.

For example, the significant loss of white fir habitat predicted in the future (2060) is cause for concern as there are hundreds of species in the Sierra Nevada that depend on White fir habitat for survival. Approximately 33 mammal species, 123 species of birds, and 17 reptile species are associated with White fir habitat (Zouhar, 2001). Most notably these species include black bears, bald eagles, and the California mountain beaver (Zouhar, 2001). White fir is also one of the most versatile lumbers, making it very desirable in the wood products industry (Zouhar, 2001). The loss of white fir in the future will have unknown economic and environmental consequences.

In contrast, the California spotted owl relies on old-growth forests, particularly Douglas fir stands (Zouhar, 2001). Douglas fir is projected to be very abundant in the landscape in the future (2060); however, since seral stage and canopy cover were not accounted for in this particular analysis, there may be an overestimation of how much old-growth Douglas fir habitat will exist across the landscape. Knowing the seral stage would help identify what portion of the landscape is old-growth forest, which is naturally more fire-tolerant and supports tremendous biodiversity (Hessburg et al., 2016).

Healthy forests tend to comprise multiple tree species across a range of seral stages. This mosaic structure creates heterogeneity within the landscape and can lead to greater resilience to disturbances such as wildfires (Campbell et al., 2018). The overall decrease in mixed forest types (i.e. mixed hardwood conifer, Sierra mixed conifer, and high elevation mixed conifer) signifies that more areas in the TCSI will be single-species stands in the future (2060) compared to 2020. Although the decrease in these mixed forest types is likely associated with changes in the climate, the loss of these heterogeneous habitats will affect ecosystem functions, abundance of native species, and resilience to disturbance (Markgraf et al., 2020; Campbell et al., 2018). The existence of this natural diversity is associated with a number of desirable functions such as variable microclimates, enhancing drought resilience and habitat diversity (Gutiérrez et al., 2017).

While long-term impacts of repeated fires on vegetation are still not very well understood, forest type conversions will affect wildlife, habitat structure, and ecosystem services in the TCSI. It is predicted that fire and climate will reduce the forest extent by 5.8% by the year 2100 (Coop et al., 2020) and our model efforts reveal significant alteration in habitat by 2060. Unfortunately, postfire climate conditions are not favorable to forest regeneration as fires are currently burning too hot or too infrequently to maintain the historic fire regime that these species rely on. However, it is evident that forest restoration and fuel reduction efforts can decrease wildfire severity and thus fire-induced mortality under future climatic conditions even in large-scale restoration projects (McCauley et al., 2019). This is especially important for fire-intolerant species such as white fir, since the increasing fire severity and frequency puts this particular species at more risk than a fire-tolerant species such as ponderosa pine (Zouhar, 2001).

In the land use data, there are important lands that are not recorded. Data layers were created with the underlying condition that each tree species occupied at least 50% of the cell they were found in in order to be represented. Thus, the gaps in the data come from species that are being represented in less than 50% of the cell or because a tree type was converted to a water body, urban, shrub (non-forest), or barren land which was not assigned a value in the initial analysis. Consequently, these alternative land cover types were not included in the analysis. Future efforts should consider inclusion of these land use types, as all land use categories should be analyzed with regard to impacts from severe wildfires, especially in vulnerable communities.

5.2.6 Interview and Modeling Overlay

For water supply, the high-yielding areas from the modeling results and stakeholder-identified areas overlap fairly extensively, particularly in the northeast and central portions of the TCSI. This indicates both that stakeholders understand where the water supply benefits they depend on originate in the region and that there is synergy between locations of stakeholder interest and natural yield, which may highlight opportunities and locations in which to pursue restoration projects.

Interestingly, the most-identified location for water supply was the northwest TCSI, near New Bullards Bar Reservoir. While New Bullards Bar Reservoir stores a tremendous amount of water for downstream communities, the area around the reservoir is actually relatively low-yielding for water. Despite this, New Bullards Bar Reservoir is an important area of interest for the stakeholders who were interviewed in the region, and restoration projects in the area could use the protection of the reservoir as motivation for prospective beneficiaries to engage with the projects.

Photo Credit: Blue Forest Conservation

6.0 CONCLUSIONS & RECOMMENDATIONS

6.1 Stakeholder Analysis Conclusions

The most frequently mentioned priority benefits include general forest health, water quality, and recreation. Overall forest health and resilience is the most important benefit in the TCSI region due to its positive influence on the provision of all other forest ecosystem services. In contrast, sedimentation is an important adverse impact for this region due to its implications for water supply and public health. Wildfires are overwhelmingly the most frequently mentioned threat within this region. While nonprofit organizations comprised the majority of our survey, interview, and mapping participants, the benefits that they did map are evenly distributed across the TCSI landscape and should not lead to an overweighting of one region within the TCSI over others.

Organizations within the TCSI value partnership and collaboration in management priorities, and this should be an important component and priority during the development of any future FRBs. Organizations interviewed may not be ready to view their forest benefits in economic terms; however, several organizations are working in collaboration with others to track benefits. This may indicate that these organizations could benefit from Blue Forest's guidance on how ecosystem services and wildfire resilience are connected to FRBs.

6.2 Modeling Conclusions

InVEST is a powerful modeling tool that can identify changes in the distributions and quantities of ecosystem services based on different scenarios. However, the InVEST model is highly dependent on the quality of the input data; future iterations of this project would benefit from more detailed climate and land cover data, as evidenced by our results. Running future scenarios at longer or otherwise different time scales may be another way to identify trends, as uncertainties about climate change preclude the creation of different precipitation and similar climate predictions at the scale of a single year.

Overall, our modeling efforts highlight that ecosystem services will inevitably be impacted by climate change and restoration in the future. However, the particular ways in which these factors will impact ecosystem services varies by each service. For water yield, modeled volumes increase in all scenarios in both 2040 and 2060, with a greater increase in scenario 1 (less restoration) compared to scenario 6 (more restoration). Higher volumes in scenario 1 may be due to a greater number of pixels in this scenario compared to scenario 6. Further investigation that considers pixels where land use changes from forest to non-forest vegetated may better elucidate the relationship between treatment scenario and water yield. Despite this, the spatial pattern of water yield remains consistent across years and scenarios. High provisioning regions occur in the northern portion and overlap with the steeply mountainous portions of the TCSI, indicating a potential association with slope. Additionally, from modeling water yield with a single land cover, we see the spatial pattern is still maintained, indicating that outputs are highly sensitive to precipitation data in particular, with land cover having a secondary impact.

Overlaying the water yield outputs with the stakeholder-identified regions of high water supply, we see that stakeholders are generally in agreement with models on high-provisioning locations of water yield. However, the most-cited location from stakeholders was New Bullards Bar Reservoir, potentially indicating that interviewees also consider the importance of reservoirs for water supply. One of the watersheds associated with New Bullards Bar Reservoir, the North Yuba River watershed, is already the target of Blue Forest's second FRB. This suggests that watersheds associated with other important dams in the region may be valuable targets for future FRB projects.

Sediment export and erosion will increase across the TCSI in the future, with northern and central TCSI experiencing the most sedimentation. The highest sediment export is expected to occur in the Yuba (per acre) and North Fork American River (total) watersheds. However, modeling illustrates that restoration activities have a positive impact on sediment export rates. The dam that will require the most focus is expected to be New Bullards Bar Reservoir, which is under the ownership of the Yuba Water Agency. However, as mentioned above, New Bullards Bar Reservoir is targeted as part of Blue Forest’s second FRB. Therefore, more emphasis should be placed on the Slab Creek Dam (southwest TCSI), which is projected to have the second largest amount of sedimentation.

Visitation in the regions within the King Fire perimeter and within a 30 km buffer dropped significantly while the fire was active. This drop-in visitation translates into a significant reduction in the economic value associated with recreation in the Eldorado National Forest, and it is likely that smoke impacts from fire may have created an even larger economic loss. If a fire similar to the King Fire were to occur again in the TCSI, we could expect to see similar recreation impacts, although some of the loss may have shifted to other recreation areas outside of the TCSI. Restoration policies to reduce wildfires, such as the development of FRBs, will have positive economic impacts by preventing this loss of economic value from recreation at national forests within the TCSI region.

Lastly, the changing climate and increasing wildfire severity in the Sierra Nevada will make forest-type conversions inevitable. Although there is not enough information on what the effects of forest type conversions will be in the future, the results of this study can help support management decisions when determining locations for restoration projects. Identifying where these changes will occur and how much of a specific forest type will be converted to another can help identify priority areas for restoration that need work immediately. Visualizing the changes occurring on the landscape level provides detail to how management plans in different portions of the TCSI can collaborate to create one resilient landscape. In conjunction with the results from the water yield, sediment retention, and recreation models, restoration projects can be maximized to encompass a full realm of ecosystem services vital to the state of California and beyond.

6.3 Overall Conclusions and Recommendations

Overall, our analyses reveal that northern portions of the TCSI, such as the Yuba River Watershed and the region around New Bullards Bar Reservoir, are important regions for the community, sedimentation, and water yield outcomes. These results validate Blue Forest's efforts to finance FRBs in Yuba River Watershed, both in the headwaters in their pilot FRB, and the region around New Bullards Bar Reservoir and Camptonville in their second FRB. Further, our analyses can also be used by Blue Forest to expand FRBs to other key regions within the TCSI. For example, HUC 10 watersheds found in this region, such as the Upper North Fork American River and Rubicon River watersheds (HUC: 1802012803 and 1802012802, respectively) are particularly important to include in future FRBs. These watersheds contain areas of high water yield and sediment export under all modeled scenarios and therefore warrant focus for future forest restoration efforts. Additionally, as identified in our stakeholder analysis, there is interest in the region for biodiversity, water quality, general forest health, recreation, water supply, and cultural and social benefits. By restoring this region, Blue Forest can achieve multiple benefits from restoration – ensuring water yield remains high while reducing the amount of erosion that occurs within the region and securing other critical ecosystem services. To ensure the success of future FRBs, we recommend the following:

- Overlay modeling results to identify key regions that provide numerous ecosystem services that are valued by stakeholders in the region. These **regions of multiple benefits should be prioritized for future FRBs** and could be more easily funded given the number of overlapping beneficiaries that might be able to contribute to an FRB.
- Utilize modeling results to **highlight the impacts of restoration on ecosystem services of particular relevance to specific stakeholders** in order to incentivize participation in future FRBs. **Sediment export modeling results could be tied to economic dredging and remediation costs** to incentivize water utilities to participate in forest restoration.

- **Water yield modeling** results revealed that **precipitation drives modeled outcomes.** As precipitation changes are difficult to predict under climate change, it is challenging to demonstrate differences between scenarios in water yield increases. Future modeling efforts should consider different timescales and include non-forested vegetation land cover to generate more robust projections.
- The **more restoration or treatment** that occurs on the landscape, the **more acres of forest (defined as 50% or more cover) will be lost**, as tree stand density is reduced and forest health is improved. Therefore, scenarios with more restoration will have less total acres of forest habitat on the landscape. Future forest conversion is difficult to generalize over the entire TCSI landscape; however, by understanding what **type of forest conversion** is likely to occur in specific areas, Blue Forest can **better connect restoration outcomes to stakeholder interests**. For example, depending on stakeholder interests, this could include prioritizing the mixed forest stands that enhance biodiversity, and are projected to decrease in acreage in the future, or prioritizing economically important single species such as white fir.
- **Using Flickr visitation modeling to directly tie wildfires to recreation economic losses** could be an effective way to motivate contributions from the recreation sector to a future FRB. The same process used for the King Fire could be replicated for other fires in areas of interest. However, further research may be needed to determine the most effective way to demonstrate recreational economic losses from wildfires and encourage new FRB participants. While use of Flickr data might be useful for analyzing fire impacts to recreation between 2005 and 2017, alternative modeling techniques may be needed since Flickr popularity has waned in recent years.
- **Participatory GIS mapping** can be a powerful tool to expand survey results to a broader group of stakeholders within the TCSI in an effort to further map and **identify regions of important ecosystem service benefits and highlight stakeholder interest in particular areas.** This technique might be particularly effective for identifying regions of cultural significance that might not be revealed from economically oriented analyses.

Further evaluation of specific sites on the ground will be necessary to determine whether they are suitable for restoration or if particular barriers, such as land ownership, topography, or prior restoration will prevent active projects in these sites. However, the findings of this study can help identify target locations and incentivize organizations to participate in innovative financing mechanisms such as the FRB to create successful large-scale forest restoration projects. The implications of this study extend beyond the TCSI landscape; development of future FRBs could use these modeling and stakeholder analysis methods to inform arguments for innovative financing and forest restoration in new locations. We hope that the results from this study will help inform management strategies and be useful as a guide in development of other large scale forest restoration projects in locations within and outside of the TCSI.

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8.0 APPENDICES

Appendix A: InVEST Methods

InVEST Inputs

1. Land Use/Land Cover (LULC)

The LULC data layer used for this project was provided by The Nature Conservancy. As stated in the Modeling Methods section, the land use data was created using LANDIS-II.

The data contained information on forest type, seral stage, and canopy cover identified through a unique California Wildlife Habitat Relationship (CWHR) code. The first or second digit of this code represents a specific tree species, the second to last digit represents the seral stage, and the last digit always represents canopy cover (Table A1.1 and A1.2).

The land cover data needed to correspond with other data layers such as the biophysical table (see below) for each submodel in InVEST. Generalizing the forest types allowed for more ease and accuracy in building the biophysical tables. Information on the parameters for each submodel was also more readily available for general forest types than information for individual tree species. We categorized the specific forest types and canopy cover in the original LULC layer into broader forest types. Using the definition provided by the Food and Agriculture Organization (FAO), forests are defined as land spanning more than 0.5 hectares with trees higher than five meters and a canopy cover of more than 10% (FAO, 2018). Although the data did not include tree height or area, we classified areas with a canopy cover greater than 10% as “forest”, while areas with less than 10% canopy cover were classified as “non-forest” (Table A1.2). Then individual forest species were categorized into five general forest types which included conifer, hardwood, mixed, shrub, and non-forest using code in R (https://github.com/teaguetran/ESM270P_code.git).

The original land use layers provided include data from 2020 through 2100 at 5-year intervals projected under the two restoration scenarios described previously. Each year had 24 iterations of each scenario. We focused on years 2020, 2040, and 2060 to compare current land cover with informative projections that were not too far into the future to reduce uncertainty. To simplify our analysis, we decided to find specific replicates for each scenario and year (2040 and 2060) that had the least and greatest variability in land use. These minimum and maximum differences represent the range of projections created due to the stochastic nature of the LANDIS model. Each run of the model created different climate conditions to account for environmental variability and uncertainty, which produced 24 different replicates of each scenario in each time frame. Using the replicate with the least amount of land use change and the replicate with the greatest change in our modeling allowed us to examine the extremes of projected land use change in the region while running the InVEST submodels in a reasonable number of times. We found that the 2020 replicates were all the same and selected one at random to represent baseline or current land use to compare to future years.

To reclassify the dataset, we used the package, stars, in R to polygonize the raster and obtain a data table with the specific number code for each cell (https://github.com/teaguetran/ESM270P_code.git). We then parsed the number codes into separate columns for each forest category and assigned character values based on the conversion in Table B1 and B2. Seral stages were not considered because we primarily focused on land cover and forest type. The forest types were classified into land cover codes (non-forest = 1, conifer = 2, hardwoods = 3, mixed = 4, shrub = 5).

Table A1.1. California Wildlife Habitat Relationship (CWHR) forest type codes reclassified into one of the five specified categories.

First 1 or 2 digits	Forest Type	Reclassified Forest Type
0	Non-forested	Non-forested
1	Aspen	Hardwood
2	Montane Hardwood	Hardwood
3	Montane Riparian	Mixed-forested
4	White Fir	Conifer
5	Red Fir	Conifer
6	Jeffrey Pine	Conifer
7	Ponderosa Pine	Conifer
8	Douglas Fir	Conifer
9	Mixed hardwood conifer	Mixed forest
10	Lodgepole Pine	Conifer
11	Sierra mixed conifer	Conifer
12	Sierra high elevation mixed conifer	Conifer
13	Juniper	Conifer
14	Chaparral	Shrub

Table A1.2. Forest and Non-forest classifications by canopy cover.

Last Digit	Canopy Cover	Reclassification Type
0	0-10%	Non-forest
1	10-25%	Forest
2	25-40%	Forest
3	40-60%	Forest
4	60-100%	Forest

The reclassified forest type data were then imported into ArcGIS Pro, where they were converted to rasters using the Polygon to Raster tool. The values of the raster cells were set as the land cover codes mentioned above.

2. Biophysical Table

a. <u>Annual Water Yield Model</u>

The biophysical table was compiled from a variety of literature sources. It contains three variables, which are associated with each land cover type included in our LULC layer through the column name lucode. The first variable is LULC_veg, which specifies which equation for actual evapotranspiration the model will use. We set this value to 1 for all vegetated land cover types except wetlands, and 0 for all other land cover types (Sharp et al., 2014) (Table A2.1).

The second variable is root_depth, the depth at which 95% of a vegetation type's roots occur. For non-vegetated land covers, this was set to -1. For vegetated non-forest land cover types (shrub), root_depth was set to 2500 mm (Sharp et al., 2014). For forest types, it was set to 9501 mm (Schenk & Jackson, 2002; Roche et al., 2020) (Table A2.1).

The third variable is Kc, the plant evapotranspiration coefficient. Kc is 0.5 for non-forest types, 1 for conifer and mixed-forest types, 0.876 for hardwood types, and 0.674 for shrub types (Sharp et al., 2014; Allen et al., 1998; Iio & Ito, 2014) (Table A2.1).

Table A2.1. Biophysical table for the Annual Water Yield model.

lucode	LULC_veg	root_depth	Kc
0	0	-1	0
1	0	-1	0.5
2	1	9501	1
3	1	9501	0.876
4	1	9501	1
5	1	2500	0.674

b. Sediment Delivery Ratio Model

The biophysical table was compiled from a variety of literature sources. It contains two variables, which are associated with each land cover type included in our LULC layer through the column name lucode. A unique integer number was given to each LULC type and each variable has an associated value derived from literature. The first variable is usle_c which is the cover-management factor (C factor) for the Universal Soil Loss Equation (USLE). This value is a floating-point value between 0 and 1 (Sharp et al., 2014). It accounts for how land cover, crops, and crop management cause soil loss to vary from losses occurring in bare fallow areas (Panagos et al., 2015). For this project, 0.00155 was used for all the forested areas, as suggested in Panagos et al. (2015) and Gurung et al. (2018) (Table A2.2). The C factor for shrub lands was estimated to be 0.0265. Since forested land can be assumed to have little soil loss in comparison to cropland, values closer to 0 were used. Non-forested areas were assigned a value of 0.45 based on values for steppes, tundra, badlands, and scattered high-altitude vegetation (Panagos et al., 2015) since most of the non-forested areas occurred along ridge lines and at high altitudes (Table A2.2).

The second variable is usle_p which is the support practice factor (P factor) for the USLE, a floating-point value between 0 and 1 (Sharp et al., 2014). The P factor measures the effect of control practices that reduce the erosion potential of the runoff by their influence on drainage patterns, runoff concentration, and runoff velocity (Soil Conservation Service, n.d.). We assumed that land in the forested areas had no soil conservation measures and thus assigned forested areas a value of 1 (Table A2.2). The P factor values for shrubland and non-forested landscapes (.85 and .2 respectively) were obtained from Panagos et al, 2015 (Table A2.2).

Table A2.2. Biophysical table for the Sediment Delivery Ratio model.

Description	lucode	usle_c	usle_p
Nonforest	1	0.45	0.5
Conifer	2	0.003	1
Hardwood	3	0.003	1
Mixed	4	0.003	1
Shrub	5	0.003	1

3. Other Data Requirements

For processing before running InVEST, all spatial data layers for the Annual Water Yield and Sediment Delivery Ratio model were reprojected into Albers Conic Equal Area.

a. Annual Water Yield Model

Additionally, the precipitation, average annual reference evapotranspiration, root restricting layer depth, and plant available water content layers were each clipped to the study area boundary using a shapefile of the TCSI boundary, then resampled to a cell size of 30 m by 30 m to match the resolution of our land use/land cover raster (Figure A1). For future years, precipitation data was sourced from Cal-Adapt showing projected future precipitation as the 30-year average from 2035-2064 (Geospatial Innovation Facility, 2021). This data was processed in the same way as the current precipitation data. The watersheds layer was also clipped to the TCSI boundary.

The Z parameter is the only parameter of the Annual Water Yield model. The Z parameter is calculated as the number of rainy days per year multiplied by 0.2 (Donohue et al., 2012). We ran the model with a Z parameter value of 7.94 based on an estimated 39.7 rainy days per year in the TCSI region.

b. Sediment Delivery Ratio Model

A total of six Digital Elevation Models from the NASA dataset that covered the TCSI region were used. These DEM raster layers were merged into one layer using the “Mosaic to New Raster” tool (Figure A5). In alignment with the InVEST user guide, the DEM was not clipped to the region of interest (Sharp et al., 2014).

The Rainfall Erosivity Index (R) and soil erodibility (K) data were collected from the same EPA data source, which consisted of a vector polygon with both variables as separate columns. To create separate rasters for each of them, we used the “Polygon to Raster” conversion tool and assigned the value field to either the R or K column (Figure A4).

Threshold flow accumulation, Kb, IC0, SDRmax, and Inax (Table C2) are all parameters that were set in the SDR model. A description of the parameters can be found in the Appendix C. These parameters were set to the values recommended by Natural Capital (Sharp et. al, 2014).

Appendix B: GIS Methods

Data analysis for habitat quality was done through ArcGIS Pro and R Studio. The repository for the code can be found at https://github.com/hweyland/gp_habitat_analysis.git.

Appendix C: InVEST Results

1. Annual Water Yield

Additional results for Annual Water Yield including maps and tabulated data.

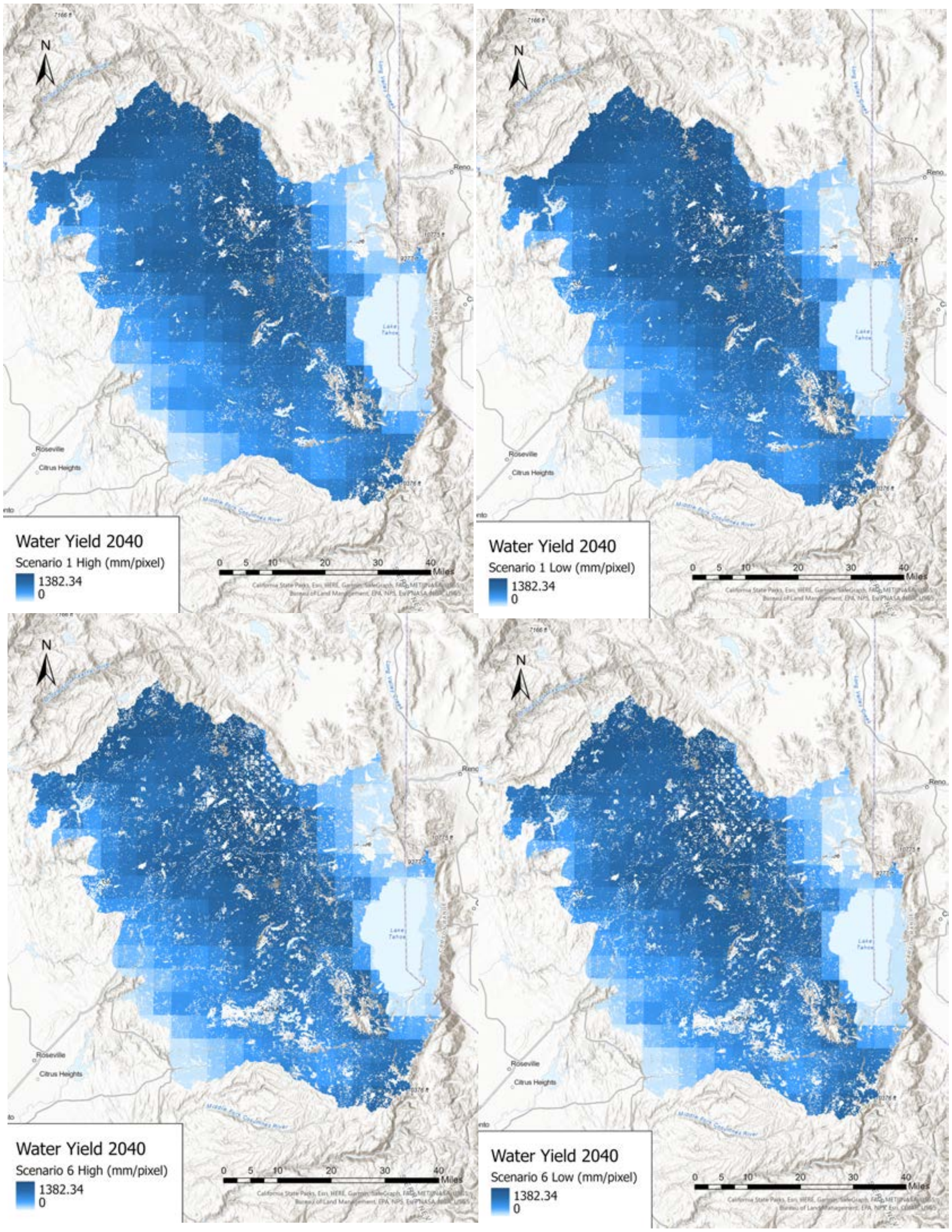


Figure C1. 1. Spatial distribution of annual water yield in the TCSI in 2040 for both restoration scenarios under low- and high-change replicates. Trends are consistent across scenarios, with high yield (darker blue) in the north and center portions of the study area. There are more no data spots in scenario 6 (bottom two images), indicating greater transition to urban, barren, or non-forest. Pixels are 900 square meters.

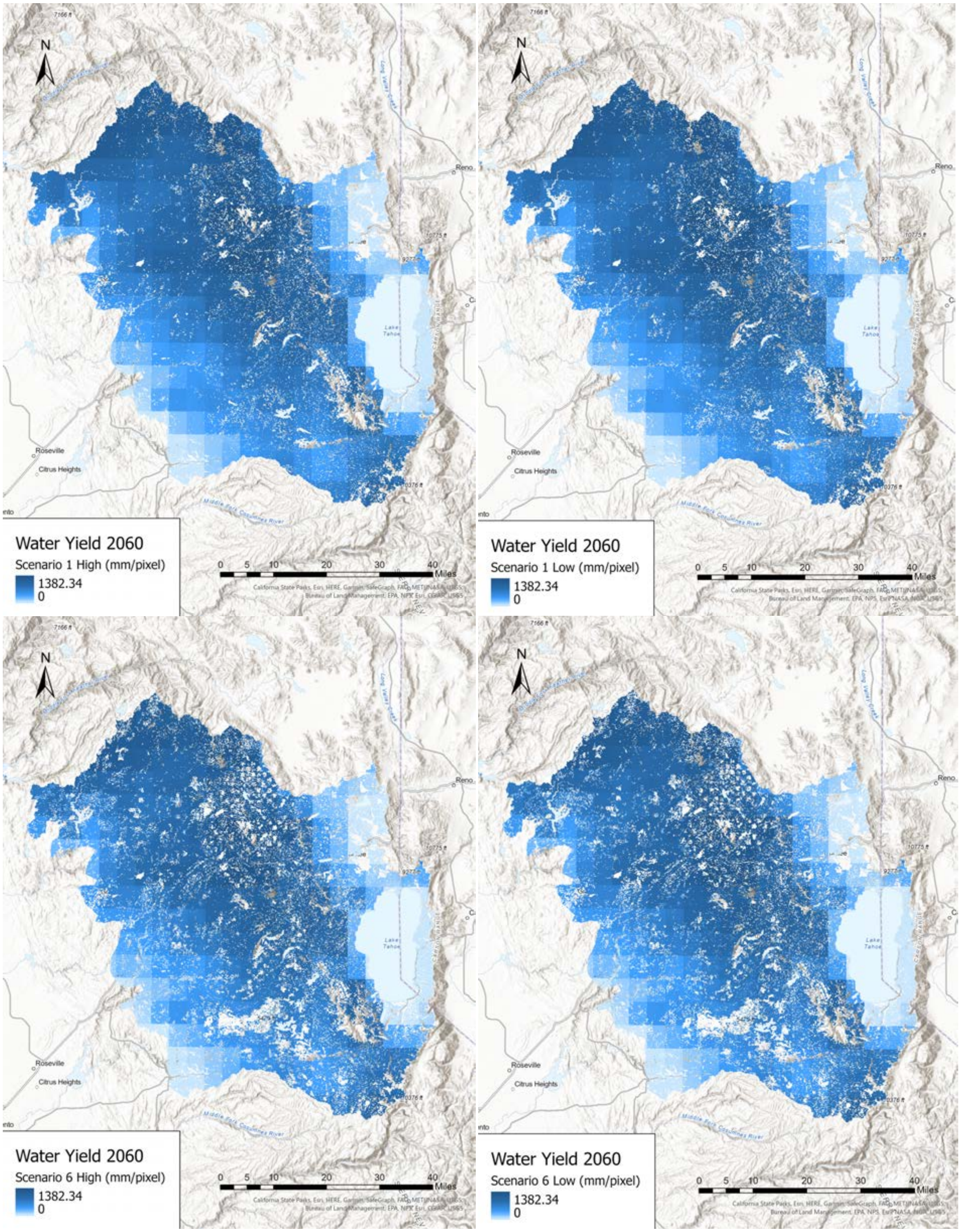
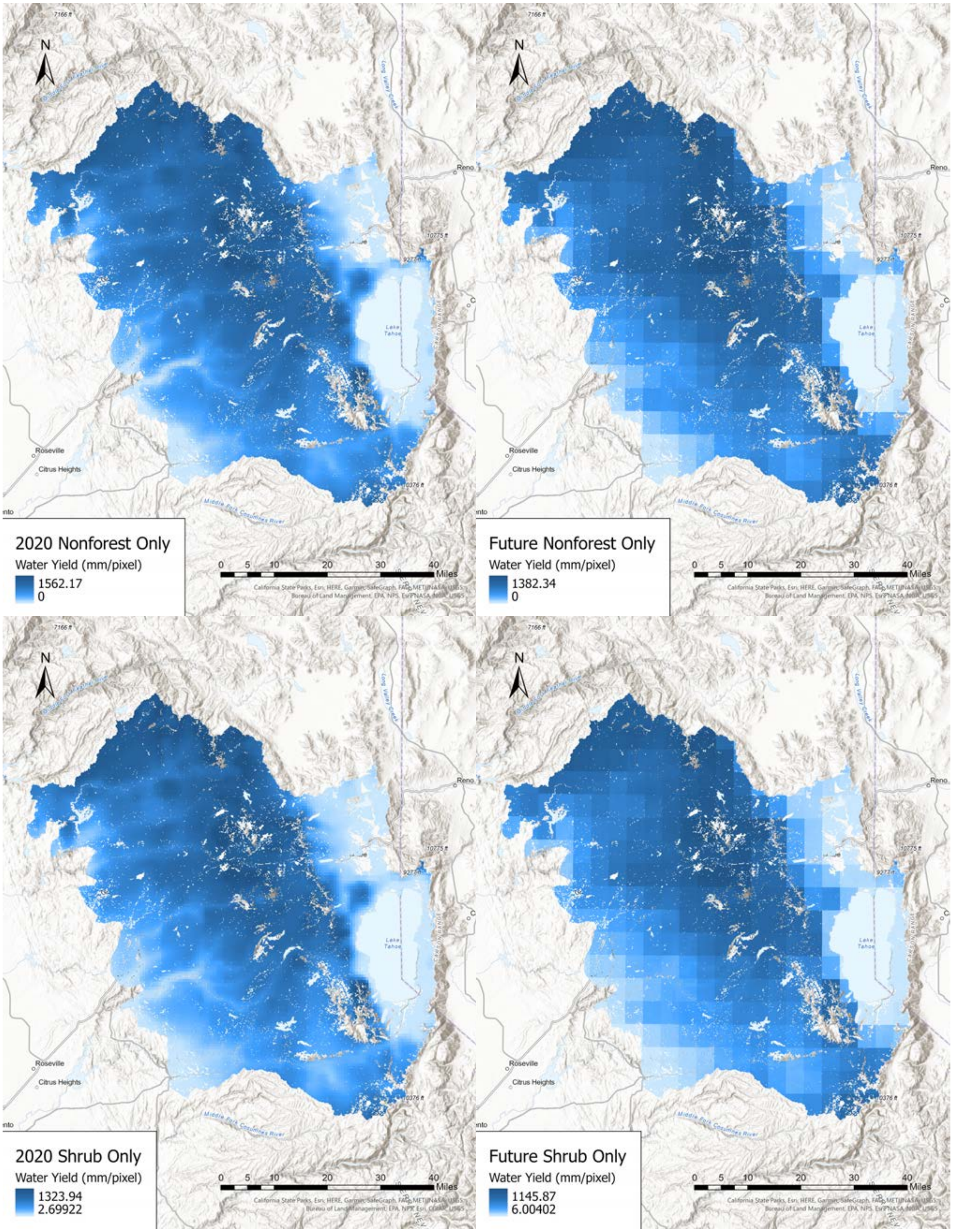
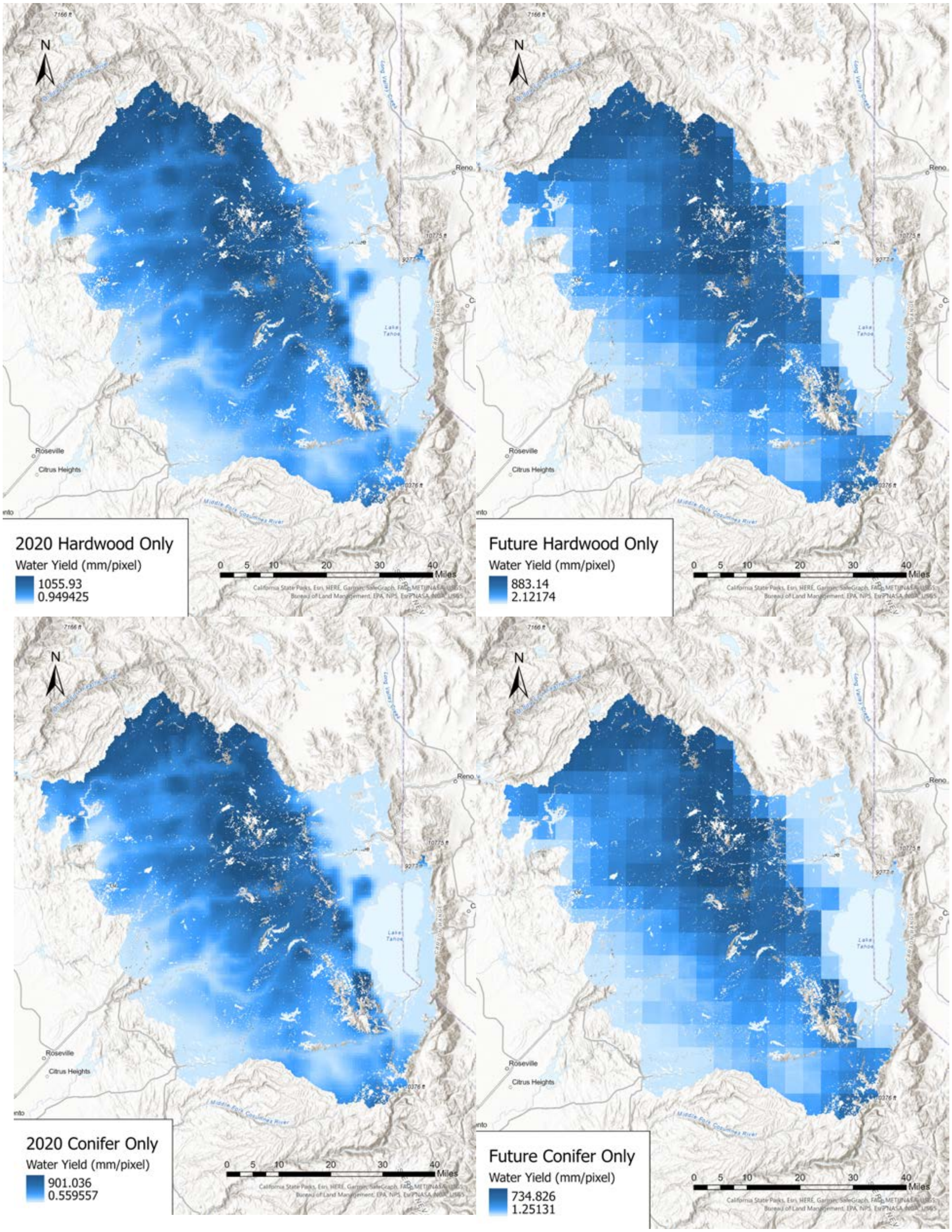


Figure C1.2. Maps of annual water yield in 2060 for both scenarios (top = scenario 1, bottom = scenario 6). Trends are consistent across scenarios and match trends in 2040: higher water yield (darker blue) is concentrated in the north and center of the region, with greater conversion to urban, barren, or non-forest (no data patches) in scenario 6 compared to scenario 1. Pixels are 900 square meters.

Additional results for annual water yield using uniform land use/land cover inputs (image continued on next page):



Additional results for annual water yield using uniform land use/land cover inputs (image continued on next page):



Additional results for annual water yield using uniform land use/land cover inputs:

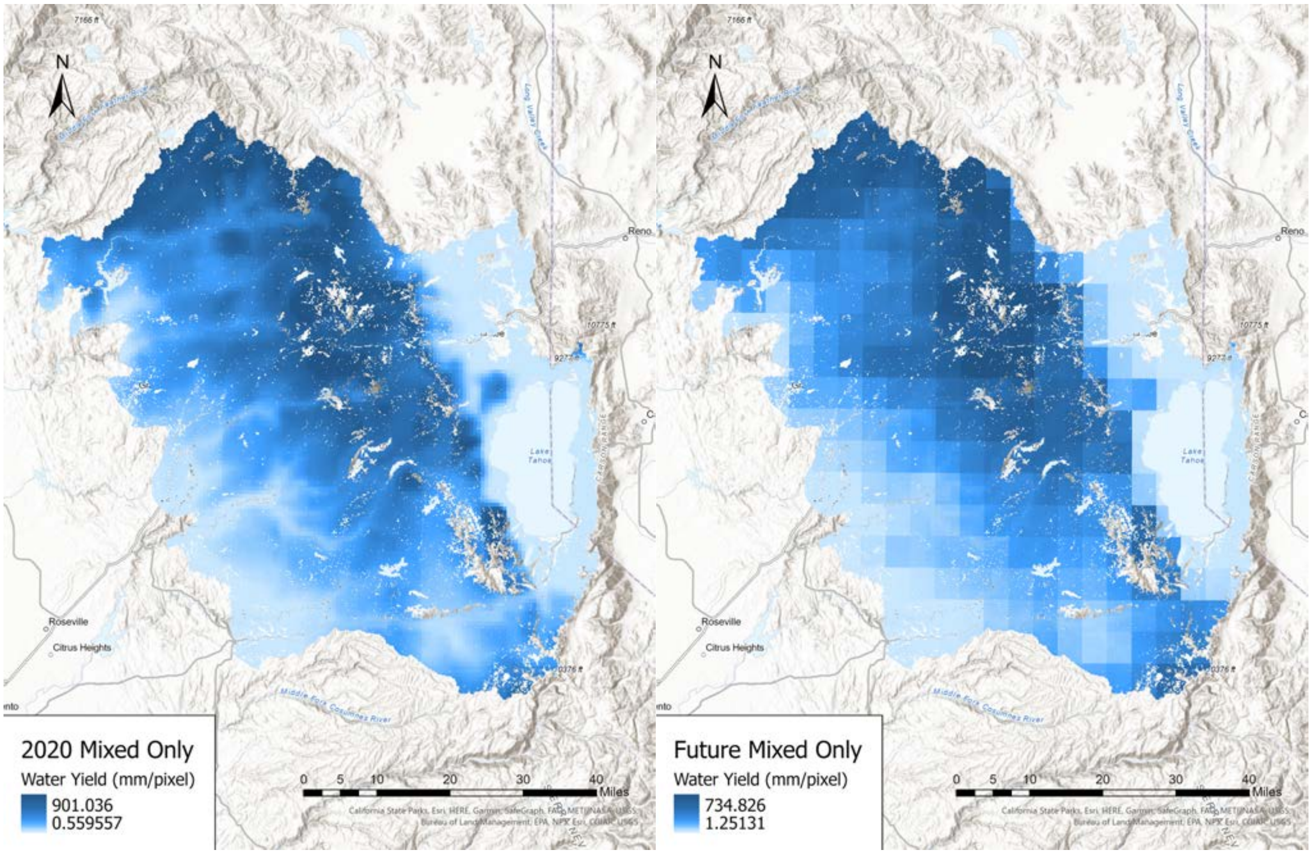


Figure C1.3 Maps of current and future annual water yield in the TCSI where the input land cover data was modified and uniformly assigned to each land cover type in turn. While absolute values of water yield (in mm/900 square m pixel) vary by land cover type, spatial trends remain consistent across land cover types and with prior mixed-land cover runs, indicating that variation in precipitation is more influential than land cover type on the spatial distribution of water yield.

Additional results for annual water yield using uniform land use/land cover inputs:

Table C1.1 Aggregated (total and per-pixel mean) annual water yield by HUC10 watersheds in the TCSI region in 2020.

2020

Subwatershed	Total Water Yield (m³)	Mean Water Yield (mm/900 m²)
Rubicon River	556,077,765.15	680.84
Upper South Yuba River	537,659,555.55	1,049.05
Upper North Fork American River	517,352,442.30	787.35
Lower North Yuba River	506,937,853.81	957.98
Middle Yuba River	432,176,783.61	794.04
Upper North Yuba River	369,379,423.54	1,009.09
Silver Creek	256,164,806.87	557.68
Upper Middle Fork American River	226,316,852.60	787.54
Lower South Yuba River	221,624,083.63	669.29
Downie River	194,465,555.28	1,035.30
Upper South Fork American River	193,860,658.56	470.83
Upper Bear River	183,194,819.48	685.47
Prosser Creek-Truckee River	171,570,490.98	342.21
North Fork Middle Fork American River	168,192,694.41	703.16
Middle North Yuba River	159,469,963.91	847.79
Silver Fork American River	157,384,702.20	546.35
General Creek-Frontal Lake Tahoe	143,840,005.41	552.41
Little Truckee River	112,981,932.46	253.22
Deer Creek	87,823,604.04	705.73
Lower North Fork American River	87,473,996.29	397.70
Upper Truckee River-Frontal Lake Tahoe	67,678,017.41	266.33
Dry Creek	62,767,344.86	556.72
Lower Middle Fork American River	60,503,013.20	280.57
Rock Creek	58,958,066.53	305.47
Middle South Fork American River	54,868,719.14	242.76
Third Creek-Frontal Lake Tahoe	36,761,981.50	257.13
Wolf Creek	35,629,106.52	472.65
Lake Tahoe	21,669,105.47	43.52
Yuba River	15,970,687.81	330.37
Weber Creek	11,770,246.11	115.39
Middle Bear River	11,104,010.07	211.46
Lower South Fork American River	3,809,774.51	103.13
Marlette Lake-Frontal Lake Tahoe	3,100,592.60	19.71
South Fork Feather River	96,782.24	1,076.03
Camp Creek	57,341.79	440.49
City of Reno-Truckee River	16,342.64	79.86
Upper Middle Fork Feather River	13,533.76	1,058.70
Sierra Valley	8,347.97	179.87
Honcut Creek	7,356.20	467.39
Middle Middle Fork Feather River	5,626.83	1,237.31
Smithneck Creek	4,028.20	137.98
North Fork Cosumnes River	2,783.84	697.03
Upper North Fork Mokelumne River	208.40	852.50
Steamboat Creek	133.17	147.93
West Fork Carson River	6.09	147.48

Additional results for annual water yield using uniform land use/land cover inputs:

Table C1.2 Aggregated (total and per-pixel mean) annual water yield by HUC10 watersheds in the TCSI region in 2040 Scenario 1.

2040 Scenario 1 High

Subwatershed	Total Water Yield (m³)	Mean Water Yield (mm/900 m²)
Rubicon River	629,060,728.13	770.19
Upper North Fork American River	623,545,197.34	948.97
Upper South Yuba River	614,494,736.68	1,198.96
Lower North Yuba River	548,347,871.97	1,036.23
Middle Yuba River	487,034,726.17	894.83
Upper North Yuba River	411,291,030.71	1,123.58
Silver Creek	285,834,213.15	622.27
Upper Middle Fork American River	262,067,577.56	911.95
Lower South Yuba River	261,596,223.64	790.00
Upper South Fork American River	239,398,731.78	581.42
Upper Bear River	215,171,233.44	805.11
Prosser Creek-Truckee River	211,623,258.50	422.10
Downie River	209,991,376.45	1,117.95
Silver Fork American River	202,747,785.98	703.83
North Fork Middle Fork American River	199,164,665.60	832.64
Middle North Yuba River	176,823,237.36	940.05
General Creek-Frontal Lake Tahoe	162,782,748.15	625.16
Little Truckee River	144,593,908.98	324.08
Upper Truckee River-Frontal Lake Tahoe	106,402,772.21	418.72
Lower North Fork American River	99,077,218.50	450.46
Deer Creek	95,640,388.04	768.54
Dry Creek	78,248,334.71	694.03
Lake Tahoe	71,263,184.23	143.14
Lower Middle Fork American River	69,026,615.31	320.10
Rock Creek	64,001,563.55	331.60
Middle South Fork American River	56,934,362.00	251.90
Third Creek-Frontal Lake Tahoe	43,745,092.94	305.97
Wolf Creek	38,816,065.11	514.93
Yuba River	17,367,923.63	359.28
Middle Bear River	15,910,802.97	303.01
Weber Creek	11,876,277.38	116.43
Lower South Fork American River	4,820,534.30	130.49
Marlette Lake-Frontal Lake Tahoe	3,331,433.63	21.18
South Fork Feather River	102,324.62	1,137.65
Camp Creek	74,253.00	570.39
City of Reno-Truckee River	16,743.72	81.82
Upper Middle Fork Feather River	14,477.65	1,132.54
Sierra Valley	11,713.02	252.37
Honcut Creek	10,859.98	690.01
Smithneck Creek	6,024.55	206.37
Middle Middle Fork Feather River	5,277.34	1,160.46
North Fork Cosumnes River	2,707.97	678.03
Upper North Fork Mokelumne River	251.46	1,028.65
Steamboat Creek	176.14	195.67
West Fork Carson River	9.54	231.10

2040 Scenario 1 Low

Subwatershed	Total Water Yield (m³)	Mean Water Yield (mm/900 m²)
Rubicon River	629,165,011.78	770.32
Upper North Fork American River	623,950,842.91	949.58
Upper South Yuba River	614,967,514.31	1,199.88
Lower North Yuba River	547,703,062.49	1,035.01
Middle Yuba River	486,882,589.92	894.55
Upper North Yuba River	411,128,620.95	1,123.14
Silver Creek	285,891,992.36	622.40
Upper Middle Fork American River	262,300,302.04	912.76
Lower South Yuba River	261,465,628.28	789.60
Upper South Fork American River	239,361,040.73	581.33
Upper Bear River	215,203,536.60	805.23
Prosser Creek-Truckee River	211,809,765.98	422.47
Downie River	209,970,519.99	1,117.84
Silver Fork American River	202,451,061.10	702.80
North Fork Middle Fork American River	198,971,479.66	831.83
Middle North Yuba River	176,703,113.66	939.41
General Creek-Frontal Lake Tahoe	162,847,188.04	625.41
Little Truckee River	144,725,828.82	324.37
Upper Truckee River-Frontal Lake Tahoe	106,215,088.00	417.98
Lower North Fork American River	99,204,164.27	451.03
Deer Creek	95,837,945.00	770.13
Dry Creek	78,197,691.58	693.59
Lake Tahoe	70,009,905.20	140.62
Lower Middle Fork American River	68,882,345.84	319.43
Rock Creek	64,078,542.31	332.00
Middle South Fork American River	57,437,127.85	254.12
Third Creek-Frontal Lake Tahoe	43,735,995.07	305.90
Wolf Creek	38,926,877.02	516.40
Yuba River	17,356,948.11	359.05
Middle Bear River	15,908,467.66	302.96
Weber Creek	11,945,656.01	117.11
Lower South Fork American River	4,823,705.52	130.57
Marlette Lake-Frontal Lake Tahoe	3,335,874.93	21.20
South Fork Feather River	102,324.62	1,137.65
Camp Creek	73,706.40	566.20
City of Reno-Truckee River	20,786.91	101.58
Upper Middle Fork Feather River	14,477.65	1,132.54
Sierra Valley	11,713.02	252.37
Honcut Creek	10,859.98	690.01
Smithneck Creek	5,906.99	202.34
Middle Middle Fork Feather River	5,277.34	1,160.46
North Fork Cosumnes River	2,707.97	678.03
Upper North Fork Mokelumne River	251.49	1,028.76
Steamboat Creek	175.69	195.18
West Fork Carson River	9.55	231.35

Additional results for annual water yield using uniform land use/land cover inputs:

Table C1.3 Aggregated (total and per-pixel mean) annual water yield by HUC10 watersheds in the TCSI region in 2040 Scenario 6.

2040 Scenario 6 High

Subwatershed	Total Water Yield (m^3)	Mean Water Yield ($mm/900\ m^2$)
Rubicon River	629,060,728.13	770.19
Upper North Fork American River	623,545,197.34	948.97
Upper South Yuba River	614,494,736.68	1,198.96
Lower North Yuba River	548,347,871.97	1,036.23
Middle Yuba River	487,034,726.17	894.83
Upper North Yuba River	411,291,030.71	1,123.58
Silver Creek	285,834,213.15	622.27
Upper Middle Fork American River	262,067,577.56	911.95
Lower South Yuba River	261,596,223.64	790.00
Upper South Fork American River	239,398,731.78	581.42
Upper Bear River	215,171,233.44	805.11
Prosser Creek-Truckee River	211,623,258.50	422.10
Downie River	209,991,376.45	1,117.95
Silver Fork American River	202,747,785.98	703.83
North Fork Middle Fork American River	199,164,665.60	832.64
Middle North Yuba River	176,823,237.36	940.05
General Creek-Frontal Lake Tahoe	162,782,748.15	625.16
Little Truckee River	144,593,908.98	324.08
Upper Truckee River-Frontal Lake Tahoe	106,402,772.21	418.72
Lower North Fork American River	99,077,218.50	450.46
Deer Creek	95,640,388.04	768.54
Dry Creek	78,248,334.71	694.03
Lake Tahoe	71,263,184.23	143.14
Lower Middle Fork American River	69,026,615.31	320.10
Rock Creek	64,001,563.55	331.60
Middle South Fork American River	56,934,362.00	251.90
Third Creek-Frontal Lake Tahoe	43,745,092.94	305.97
Wolf Creek	38,816,065.11	514.93[2]
Yuba River	17,367,923.63	359.28
Middle Bear River	15,910,802.97	303.01
Weber Creek	11,876,277.38	116.43
Lower South Fork American River	4,820,534.30	130.49
Marlette Lake-Frontal Lake Tahoe	3,331,433.63	21.18
South Fork Feather River	102,324.62	1,137.65
Camp Creek	74,253.00	570.39
City of Reno-Truckee River	16,743.72	81.82
Upper Middle Fork Feather River	14,477.65	1,132.54
Sierra Valley	11,713.02	252.37
Honcut Creek	10,859.98	690.01
Smithneck Creek	6,024.55	206.37
Middle Middle Fork Feather River	5,277.34	1,160.46
North Fork Cosumnes River	2,707.97	678.03
Upper North Fork Mokelumne River	251.46	1,028.65
Steamboat Creek	176.14	195.67
West Fork Carson River	9.54	231.10

2040 Scenario 6 Low

Subwatershed	Total Water Yield (m^3)	Mean Water Yield ($mm/900\ m^2$)
Rubicon River	627,361,132.71	768.11
Upper North Fork American River	614,335,354.19	934.95
Upper South Yuba River	611,728,824.51	1,193.57
Lower North Yuba River	538,875,804.40	1,018.33
Middle Yuba River	475,018,041.55	872.75
Upper North Yuba River	407,468,992.09	1,113.14
Silver Creek	281,474,864.62	612.78
Upper Middle Fork American River	261,278,053.19	909.20
Lower South Yuba River	255,097,704.13	770.37
Upper South Fork American River	238,467,032.27	579.16
Upper Bear River	211,179,129.43	790.18
Prosser Creek-Truckee River	210,626,493.46	420.11
Downie River	209,726,511.12	1,116.54
Silver Fork American River	206,096,426.29	715.45
North Fork Middle Fork American River	197,099,475.45	824.01
Middle North Yuba River	175,423,854.16	932.61
General Creek-Frontal Lake Tahoe	162,791,915.65	625.19
Little Truckee River	144,557,766.43	323.99
Upper Truckee River-Frontal Lake Tahoe	107,340,917.43	422.41
Lower North Fork American River	94,941,983.81	431.66
Deer Creek	94,522,560.00	759.56
Dry Creek	75,649,902.76	670.99
Lake Tahoe	71,476,435.06	143.57
Lower Middle Fork American River	66,091,844.20	306.49
Rock Creek	60,911,396.71	315.59
Middle South Fork American River	50,265,107.81	222.39
Third Creek-Frontal Lake Tahoe	43,223,655.74	302.32
Wolf Creek	38,732,999.34	513.83
Yuba River	16,746,188.24	346.42
Middle Bear River	15,961,002.82	303.96
Weber Creek	11,809,336.42	115.77
Lower South Fork American River	4,702,844.85	127.30
Marlette Lake-Frontal Lake Tahoe	3,362,627.62	21.37
South Fork Feather River	105,339.00	1,171.17
Camp Creek	74,210.86	570.07
City of Reno-Truckee River	20,044.52	97.95
Upper Middle Fork Feather River	14,887.00	1,164.56
Sierra Valley	11,713.02	252.37
Honcut Creek	10,859.98	690.01
Smithneck Creek	5,906.99	202.34
Middle Middle Fork Feather River	5,277.34	1,160.46
North Fork Cosumnes River	2,707.97	678.03
Upper North Fork Mokelumne River	250.75	1,025.75
Steamboat Creek	176.26	195.80
West Fork Carson River	9.66	234.00

Additional results for annual water yield using uniform land use/land cover inputs:

Table C1.4 Aggregated (total and per-pixel mean) annual water yield by HUC10 watersheds in the TCSI region in 2060 Scenario 1.

2060 Scenario 1 High

Subwatershed	Total Water Yield (m³)	Mean Water Yield (mm/900 m²)
Rubicon River	624,897,980.88	765.10
Upper North Fork American River	621,564,035.23	945.95
Upper South Yuba River	614,206,251.56	1,198.40
Lower North Yuba River	547,212,228.80	1,034.08
Middle Yuba River	483,613,534.10	888.54
Upper North Yuba River	410,538,790.03	1,121.53
Silver Creek	284,476,536.73	619.31
Lower South Yuba River	260,509,093.90	786.72
Upper Middle Fork American River	260,263,255.01	905.67
Upper South Fork American River	238,006,257.61	578.04
Upper Bear River	214,680,993.06	803.28
Prosser Creek-Truckee River	210,435,440.08	419.73
Downie River	209,987,614.32	1,117.93
Silver Fork American River	202,706,365.93	703.68
North Fork Middle Fork American River	197,590,902.79	826.06
Middle North Yuba River	176,753,720.55	939.68
General Creek-Frontal Lake Tahoe	162,809,333.51	625.26
Little Truckee River	144,835,037.30	324.62
Upper Truckee River-Frontal Lake Tahoe	106,081,118.55	417.46
Lower North Fork American River	99,149,631.31	450.79
Deer Creek	95,905,461.56	770.67
Dry Creek	78,523,912.12	696.48
Lower Middle Fork American River	69,122,599.63	320.54
Lake Tahoe	66,871,368.12	134.32
Rock Creek	64,004,589.68	331.62
Middle South Fork American River	56,440,666.22	249.71
Third Creek-Frontal Lake Tahoe	43,508,848.04	304.31
Wolf Creek	39,074,648.90	518.36
Yuba River	17,580,583.21	363.68
Middle Bear River	15,735,038.88	299.66
Weber Creek	11,988,259.82	117.53
Lower South Fork American River	4,808,589.46	130.17
Marlette Lake-Frontal Lake Tahoe	3,326,187.48	21.14
South Fork Feather River	99,855.24	1,110.20
Camp Creek	73,786.39	566.81
City of Reno-Truckee River	21,313.16	104.15
Upper Middle Fork Feather River	13,863.62	1,084.51
Sierra Valley	11,713.02	252.37
Honcut Creek	10,859.98	690.01
Middle Middle Fork Feather River	5,178.63	1,138.76
Smithneck Creek	4,185.76	143.38
North Fork Cosumnes River	2,707.97	678.03
Upper North Fork Mokelumne River	251.46	1,028.66
Steamboat Creek	177.42	197.09
West Fork Carson River	9.57	231.83

2060 Scenario 1 Low

Subwatershed	Total Water Yield (m³)	Mean Water Yield (mm/900 m²)
Rubicon River	623,871,551.90	763.84
Upper North Fork American River	621,972,040.82	946.57
Upper South Yuba River	612,385,173.47	1,194.85
Lower North Yuba River	547,010,124.15	1,033.70
Middle Yuba River	483,867,691.29	889.01
Upper North Yuba River	410,629,245.84	1,121.77
Silver Creek	284,673,316.30	619.74
Lower South Yuba River	260,747,940.21	787.44
Upper Middle Fork American River	260,280,283.51	905.73
Upper South Fork American River	237,699,864.13	577.30
Upper Bear River	215,260,837.99	805.45
Prosser Creek-Truckee River	210,611,083.53	420.08
Downie River	209,640,137.96	1,116.08
Silver Fork American River	202,799,500.19	704.01
North Fork Middle Fork American River	197,108,831.59	824.05
Middle North Yuba River	176,665,681.07	939.21
General Creek-Frontal Lake Tahoe	162,502,403.34	624.08
Little Truckee River	145,594,808.28	326.32
Upper Truckee River-Frontal Lake Tahoe	106,143,565.21	417.70
Lower North Fork American River	99,022,033.29	450.21
Deer Creek	95,535,862.45	767.70
Dry Creek	78,091,143.12	692.64
Lower Middle Fork American River	69,101,905.47	320.45
Lake Tahoe	68,505,421.48	137.60
Rock Creek	63,948,319.20	331.32
Middle South Fork American River	55,644,393.05	246.19
Third Creek-Frontal Lake Tahoe	43,523,066.00	304.41
Wolf Creek	38,943,945.23	516.63
Yuba River	17,315,311.42	358.19
Middle Bear River	16,083,321.59	306.29
Weber Creek	11,887,505.42	116.54
Lower South Fork American River	4,812,750.68	130.28
Marlette Lake-Frontal Lake Tahoe	3,334,726.26	21.20
South Fork Feather River	102,324.62	1,137.65
Camp Creek	74,253.00	570.39
City of Reno-Truckee River	16,743.72	81.82
Upper Middle Fork Feather River	13,863.62	1,084.51
Sierra Valley	11,713.02	252.37
Honcut Creek	10,859.98	690.01
Smithneck Creek	6,024.55	206.37
Middle Middle Fork Feather River	5,277.34	1,160.46
Upper North Fork Mokelumne River	251.47	1,028.70
Steamboat Creek	177.42	197.09
West Fork Carson River	9.62	233.16

Additional results for annual water yield using uniform land use/land cover inputs:

Table C1.5 Aggregated (total and per-pixel mean) annual water yield by HUC10 watersheds in the TCSI region in 2060 Scenario 6.

2060 Scenario 6 High

Subwatershed	Total Water Yield (m^3)	Mean Water Yield (mm/900 m^2)
Rubicon River	624,304,833.13	764.37
Upper North Fork American River	610,196,588.60	928.65
Upper South Yuba River	608,550,875.61	1,187.36
Lower North Yuba River	530,718,672.38	1,002.92
Middle Yuba River	466,539,900.74	857.17
Upper North Yuba River	403,081,867.34	1,101.16
Silver Creek	278,505,002.95	606.31
Upper Middle Fork American River	259,835,814.80	904.18
Lower South Yuba River	253,091,120.03	764.31
Upper South Fork American River	236,308,755.35	573.92
Downie River	209,318,150.60	1,114.37
Prosser Creek-Truckee River	208,414,950.01	415.70
Upper Bear River	208,011,745.68	778.32
Silver Fork American River	205,353,625.02	712.87
North Fork Middle Fork American River	195,841,060.33	818.75
Middle North Yuba River	174,539,338.81	927.91
General Creek-Frontal Lake Tahoe	162,549,489.85	624.26
Little Truckee River	144,791,809.59	324.52
Upper Truckee River-Frontal Lake Tahoe	109,681,726.85	431.63
Deer Creek	94,363,706.00	758.28
Lower North Fork American River	92,113,633.33	418.80
Dry Creek	73,739,928.61	654.05
Lake Tahoe	65,972,470.53	132.51
Lower Middle Fork American River	64,721,532.84	300.13
Rock Creek	60,402,758.50	312.95
Middle South Fork American River	49,467,153.66	218.86
Third Creek-Frontal Lake Tahoe	42,195,778.49	295.13
Wolf Creek	38,686,966.73	513.22
Yuba River	16,028,299.41	331.56
Middle Bear River	15,864,396.07	302.12
Weber Creek	11,985,737.74	117.50
Lower South Fork American River	4,733,084.13	128.12
Marlette Lake-Frontal Lake Tahoe	3,395,104.50	21.58
South Fork Feather River	104,331.76	1,159.97
Camp Creek	74,210.86	570.07
City of Reno-Truckee River	20,958.89	102.42
Upper Middle Fork Feather River	14,887.00	1,164.56
Sierra Valley	11,713.02	252.37
Honcut Creek	10,859.98	690.01
Smithneck Creek	5,906.99	202.34
Middle Middle Fork Feather River	5,507.74	1,211.13
Upper North Fork Mokelumne River	250.54	1,024.88
Steamboat Creek	178.73	198.54
West Fork Carson River	9.78	236.95

2060 Scenario 6 Low

Subwatershed	Total Water Yield (m^3)	Mean Water Yield (mm/900 m^2)
Rubicon River	622,862,329.80	762.61
Upper North Fork American River	613,396,272.63	933.52
Upper South Yuba River	608,102,055.54	1,186.49
Lower North Yuba River	534,155,577.75	1,009.41
Middle Yuba River	468,106,184.92	860.05
Upper North Yuba River	402,867,808.25	1,100.57
Silver Creek	281,075,415.56	611.91
Upper Middle Fork American River	259,685,515.11	903.66
Lower South Yuba River	251,734,734.57	760.22
Upper South Fork American River	236,420,345.16	574.19
Downie River	209,022,947.60	1,112.80
Upper Bear River	208,749,305.84	781.08
Prosser Creek-Truckee River	208,701,466.95	416.27
Silver Fork American River	205,498,010.91	713.37
North Fork Middle Fork American River	196,021,428.84	819.50
Middle North Yuba River	174,561,091.31	928.02
General Creek-Frontal Lake Tahoe	162,397,050.41	623.68
Little Truckee River	146,095,934.05	327.44
Upper Truckee River-Frontal Lake Tahoe	106,404,687.39	418.73
Deer Creek	94,965,420.43	763.12
Lower North Fork American River	92,648,639.59	421.23
Lake Tahoe	73,925,113.79	148.49
Dry Creek	73,468,573.01	651.64
Lower Middle Fork American River	66,123,600.23	306.63
Rock Creek	60,151,325.13	311.65
Middle South Fork American River	48,838,867.23	216.08
Third Creek-Frontal Lake Tahoe	42,690,371.58	298.59
Wolf Creek	38,655,998.26	512.81
Yuba River	16,153,823.08	334.16
Middle Bear River	15,823,713.19	301.35
Weber Creek	11,795,894.86	115.64
Lower South Fork American River	4,699,425.56	127.21
Marlette Lake-Frontal Lake Tahoe	3,364,225.94	21.38
South Fork Feather River	103,235.15	1,147.78
Camp Creek	74,253.00	570.39
City of Reno-Truckee River	17,422.52	85.14
Upper Middle Fork Feather River	14,477.65	1,132.54
Honcut Creek	10,859.98	690.01
Sierra Valley	9,869.19	212.64
Smithneck Creek	5,672.36	194.30
Middle Middle Fork Feather River	5,178.63	1,138.76
Upper North Fork Mokelumne River	251.48	1,028.72
Steamboat Creek	173.08	192.27
West Fork Carson River	9.53	230.84

2. Sediment Delivery Ratio

Additional results for Annual Water Yield including maps and tabulated data.

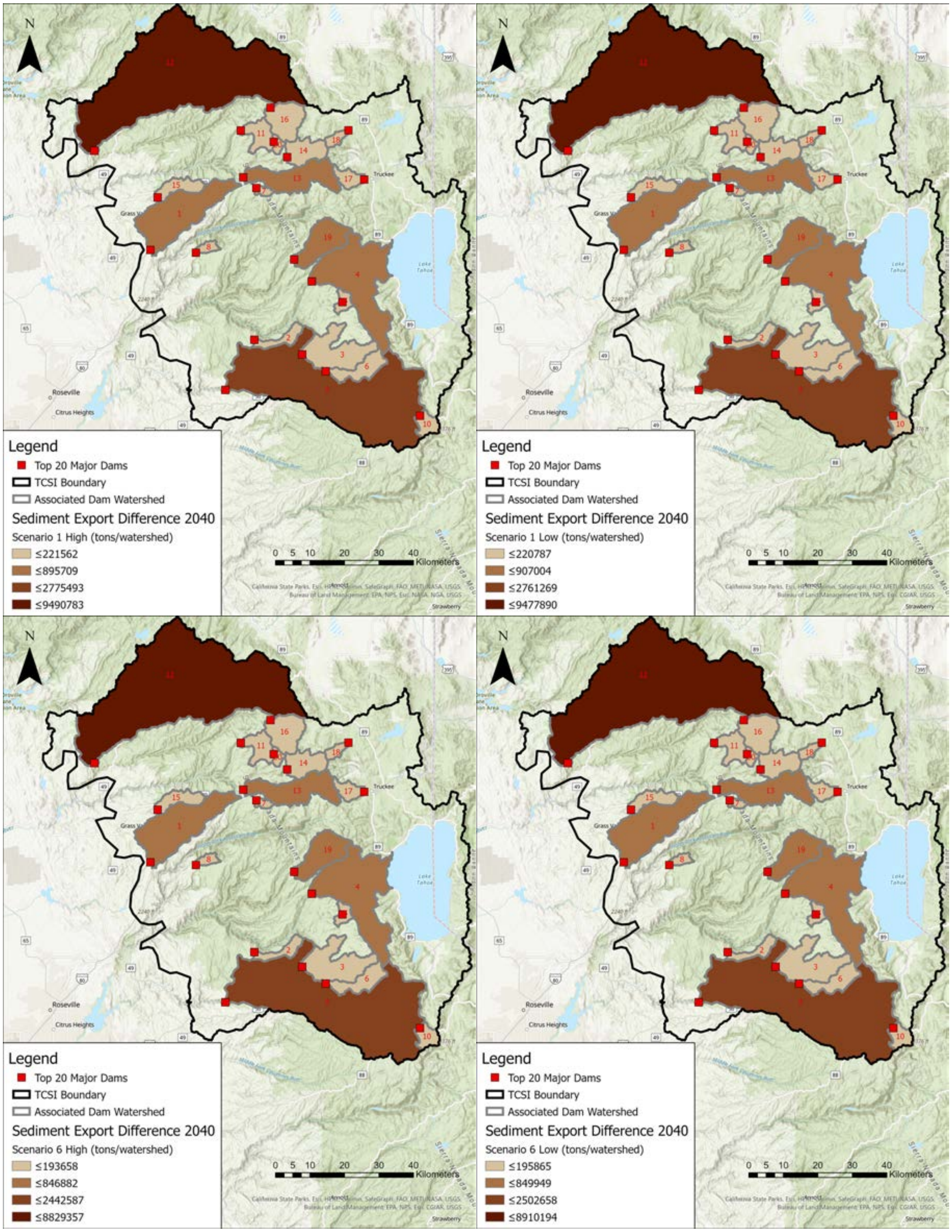


Figure C2.1 Collage of maps that show sediment retention differences between current (2020) land cover and projected 2040 land cover scenarios and replicates. The sum of differences for each associated dam watershed created from HUC 12 boundaries is displayed.

Additional results for sediment retention including maps and tabulated data.

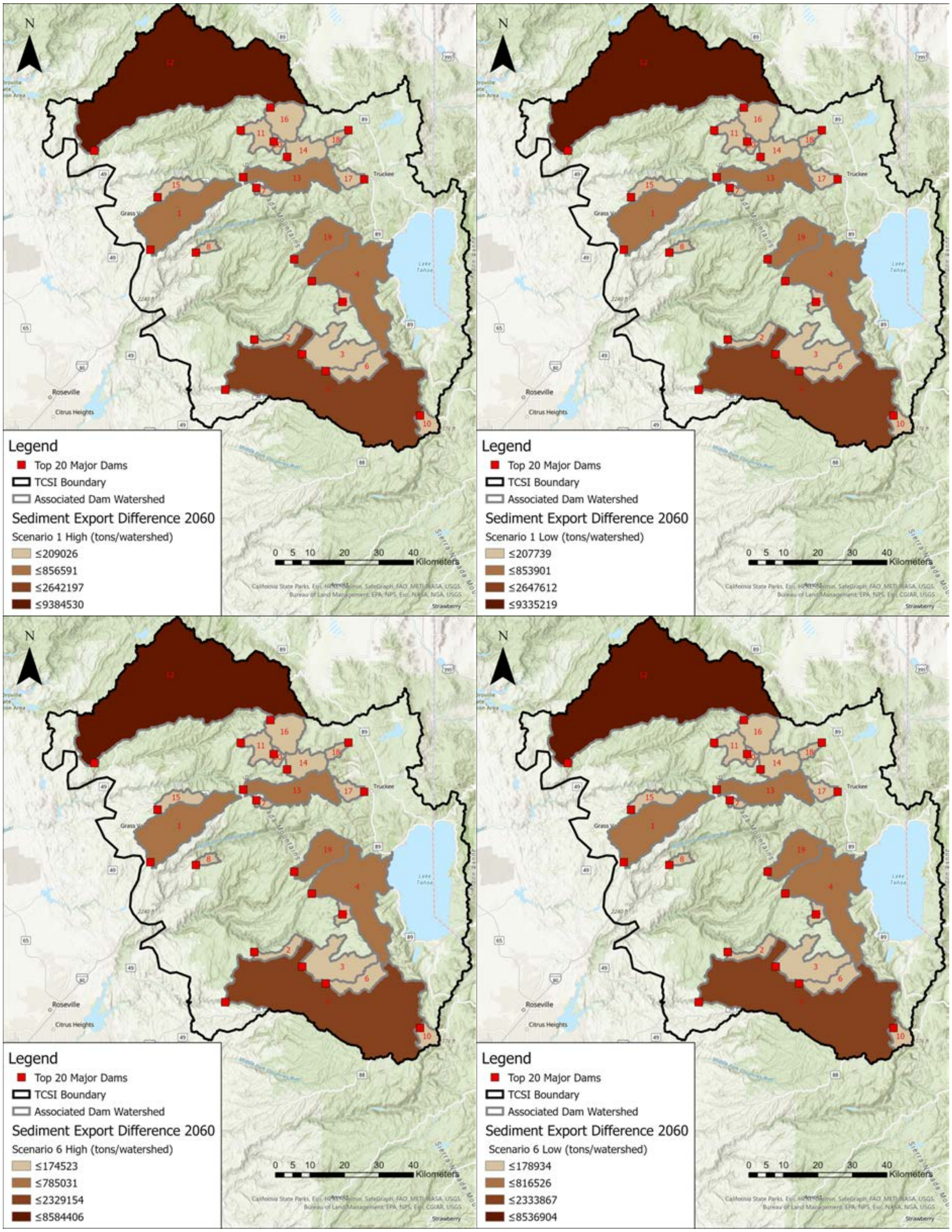


Figure C2.2. Collage of maps that show sediment retention differences between current (2020) land cover and projected 2060 land cover scenarios and replicates. The sum of differences for each associated dam watershed created from HUC 12 boundaries is displayed.

Additional results for sediment retention.

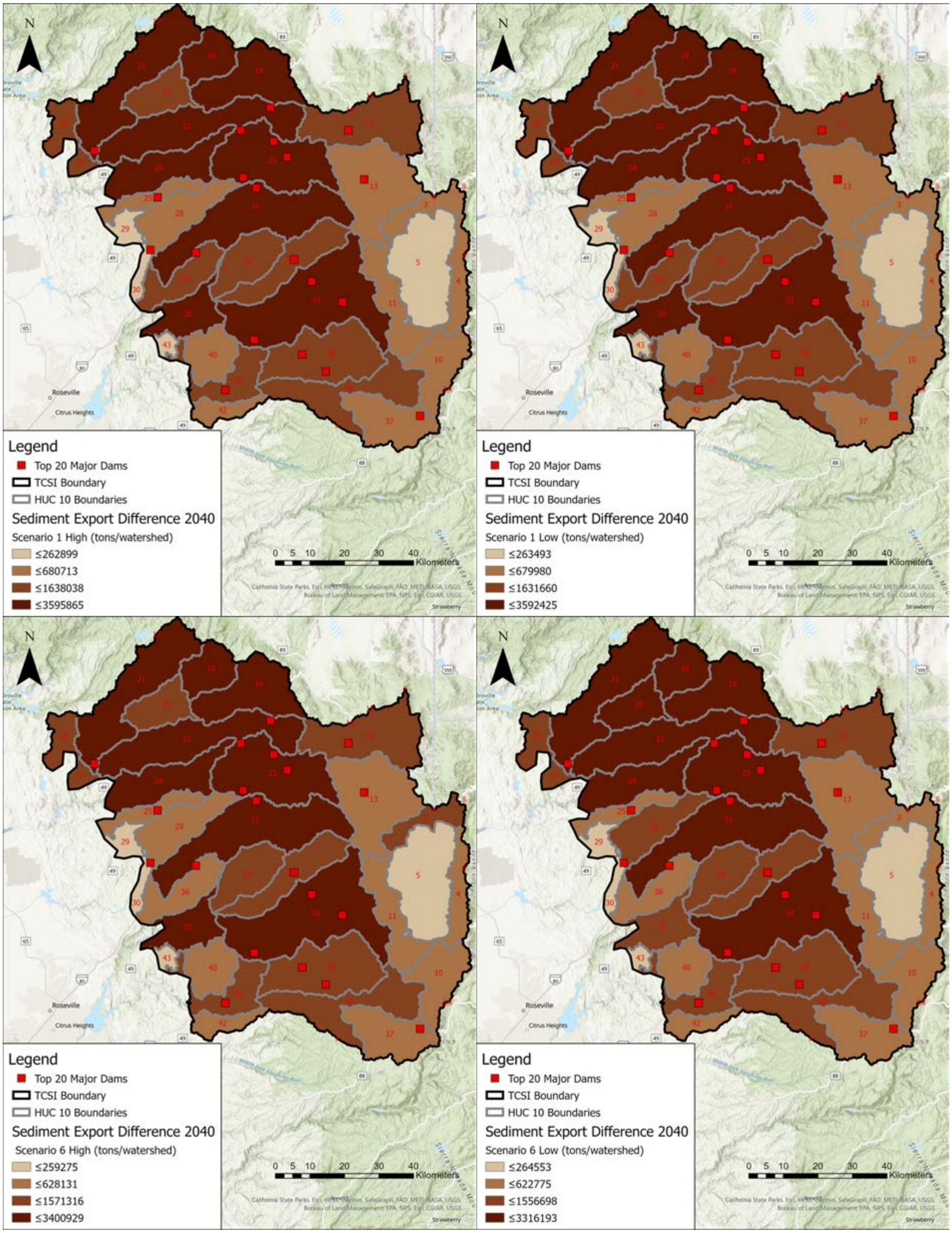


Figure C2.3. Collage of maps that show sediment retention differences between current (2020) land cover and projected 2040 land cover scenarios and replicates. The sum of differences for each HUC 10 watershed is displayed.

Additional results for sediment retention.

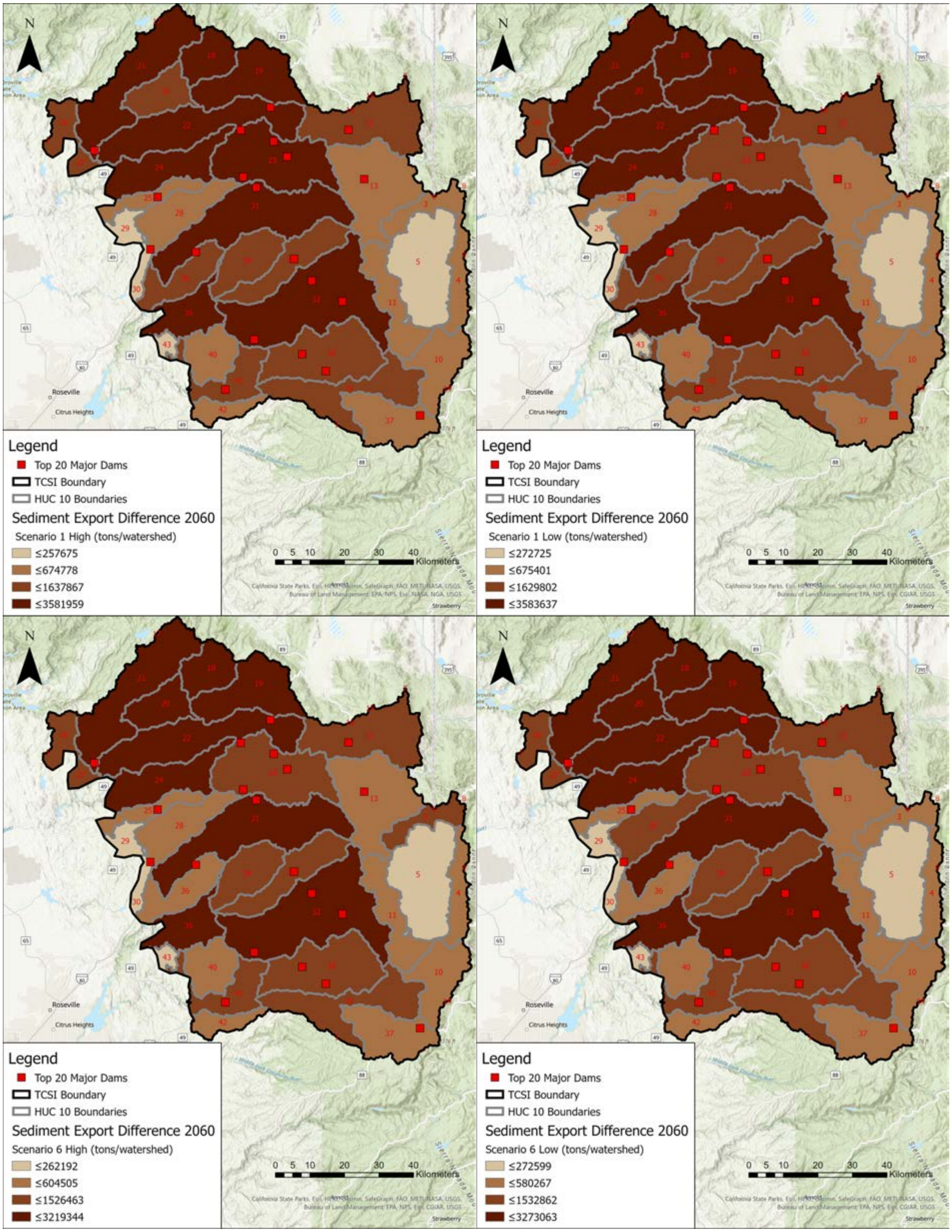


Figure C2.4. Collage of maps that show sediment retention differences between current (2020) land cover and projected 2060 land cover scenarios and replicates. The sum of differences for each HUC 10 watershed is displayed.

Additional results for sediment retention.

Table C2.1. HUC 10 watersheds within TCSI, along with a unique Watershed ID and area.

HUC 10 Watershed Information

Watershed ID	HUC10	Subwatershed Name	Area in TCSI (km²)
1	1,802,015,901	Honcut Creek	0.0028255
2	1,804,001,301	Camp Creek	0.1222698
3	1,605,010,101	Third Creek-Frontal Lake Tahoe	142.9764079
4	1,605,010,102	Marlette Lake-Frontal Lake Tahoe	157.3505375
5	1,605,010,105	Lake Tahoe	497.8622929
10	1,605,010,103	Upper Truckee River-Frontal Lake Tahoe	254.1131516
11	1,605,010,104	General Creek-Frontal Lake Tahoe	260.3858440
12	1,605,010,201	Little Truckee River	446.1775874
13	1,605,010,202	Prosser Creek-Truckee River	501.3673104
17	1,802,012,306	South Fork Feather River	0.0312085
18	1,802,012,501	Downie River	187.8408940
19	1,802,012,502	Upper North Yuba River	366.0698560
20	1,802,012,503	Middle North Yuba River	188.0997095
21	1,802,012,504	Lower North Yuba River	529.1828403
22	1,802,012,505	Middle Yuba River	544.2777995
23	1,802,012,506	Upper South Yuba River	512.5222995
24	1,802,012,507	Lower South Yuba River	331.1249018
25	1,802,012,508	Deer Creek	124.4341299
26	1,802,012,509	Dry Creek	112.7491510
27	1,802,012,510	Yuba River	48.3431015
28	1,802,012,601	Upper Bear River	267.2559254
29	1,802,012,602	Wolf Creek	75.3806262
30	1,802,012,603	Middle Bear River	52.4898726
31	1,802,012,801	Upper North Fork American River	657.0777381
32	1,802,012,802	Rubicon River	816.7558585
33	1,802,012,803	Upper Middle Fork American River	287.3714509
34	1,802,012,804	North Fork Middle Fork American River	239.1962756
35	1,802,012,805	Lower Middle Fork American River	215.6351462
36	1,802,012,806	Lower North Fork American River	219.9483951
37	1,802,012,901	Silver Fork American River	288.0892342
38	1,802,012,902	Silver Creek	459.3406749
39	1,802,012,903	Upper South Fork American River	411.7553330
40	1,802,012,904	Rock Creek	193.0072517
41	1,802,012,905	Middle South Fork American River	226.0125293
42	1,802,012,906	Weber Creek	102.0224240
43	1,802,012,907	Lower South Fork American River	36.9370728

Table C2.2. Watershed associated with the top 20 dams within TCSI

Dam Watershed Information

Watershed ID	Subwatershed Name	Area in TCSI (km²)
1	Rollins	267.2560
2	Mark Edson	38.9313
3	Union Valley	161.7430
4	Lower Hell Hole	370.5510
5	Loon Lake	22.7784
6	Ice House	70.1567
7	Lake Valley	11.7052
8	Sugar Pine	16.8903
9	Slab Creek	956.7200
10	Caples Lake	35.6429
11	Bowman	57.7505
12	New Bullards Bar	1,269.4301
13	Lake Spaulding	165.7050
14	Lake Fordyce	74.3542
15	Scotts Flat	52.4154
16	Jackson Meadows	96.7672
17	Donner Lake	34.9456
18	Independence	19.7179
19	L. L. Anderson	122.1380
20	French Lake	13.2631

Additional results for sediment retention.

Table C2.3. Sediment export differences between 2040 scenarios and replicates and 2020 summed by HUC 10 watersheds.

2040 Scenarios & Replicates

Watershed ID	Subwatershed Name	Sediment Export Difference Scenario 1 High (tons)	Sediment Export Difference Scenario 1 Low (tons)	Sediment Export Difference Scenario 6 High (tons)	Sediment Export Difference Scenario 6 Low (tons)
17	South Fork Feather River	0	0	0	0
2	Camp Creek	2	6	2	7
1	Honcut Creek	5	5	5	5
5	Lake Tahoe	77	86	79	85
4	Marlette Lake-Frontal Lake Tahoe	91	91	50	91
43	Lower South Fork American River	122,779	123,008	119,815	118,999
29	Wolf Creek	249,897	237,874	246,813	247,984
30	Middle Bear River	262,899	263,493	259,275	264,553
10	Upper Truckee River-Frontal Lake Tahoe	319,011	314,898	318,563	315,345
11	General Creek-Frontal Lake Tahoe	322,070	322,239	310,726	312,072
25	Deer Creek	368,267	367,994	320,248	352,572
42	Weber Creek	392,659	390,534	380,503	389,011
37	Silver Fork American River	532,023	534,737	486,674	494,609
40	Rock Creek	554,678	556,588	483,099	485,127
13	Prosser Creek-Truckee River	595,537	595,649	541,752	576,489
3	Third Creek-Frontal Lake Tahoe	674,518	672,851	671,144	622,126
28	Upper Bear River	680,713	679,980	628,131	640,066
41	Middle South Fork American River	724,090	724,551	651,313	665,409
36	Lower North Fork American River	733,490	731,848	588,217	622,775
38	Silver Creek	811,291	813,377	678,686	686,495
26	Dry Creek	1,031,534	1,032,123	981,277	974,339
27	Yuba River	1,282,633	1,285,676	1,145,663	1,189,046
12	Little Truckee River	1,323,242	1,295,719	1,316,034	1,284,691
39	Upper South Fork American River	1,371,366	1,351,512	1,245,280	1,282,146
33	Upper Middle Fork American River	1,601,987	1,609,159	1,545,965	1,556,698
34	North Fork Middle Fork American River	1,614,789	1,612,251	1,515,231	1,541,020
20	Middle North Yuba River	1,638,038	1,631,660	1,571,316	1,581,361
35	Lower Middle Fork American River	1,678,875	1,684,922	1,970,377	1,510,150
23	Upper South Yuba River	1,725,627	1,718,401	1,605,387	1,627,410
18	Downie River	1,925,042	1,918,075	1,910,875	1,895,891
24	Lower South Yuba River	2,032,978	2,027,715	1,923,575	1,930,075
19	Upper North Yuba River	2,585,871	2,566,173	2,310,715	2,345,820
22	Middle Yuba River	2,813,367	2,792,583	2,608,986	2,632,530
32	Rubicon River	3,186,114	3,201,590	2,992,969	2,959,839
21	Lower North Yuba River	3,392,564	3,409,547	3,077,374	3,129,957
31	Upper North Fork American River	3,595,865	3,592,425	3,400,929	3,316,193

Additional results for sediment retention.

Table C2.4. Sediment export differences between 2040 scenarios and replicates and 2020 summed by HUC 10 watersheds.

2060 Scenarios & Replicates

Watershed ID	Subwatershed Name	Sediment Export Difference Scenario 1 High (tons)	Sediment Export Difference Scenario 1 Low (tons)	Sediment Export Difference Scenario 6 High (tons)	Sediment Export Difference Scenario 6 Low (tons)
17	South Fork Feather River	0	0	0	0
2	Camp Creek	6	2	7	2
1	Honcut Creek	5	5	5	5
5	Lake Tahoe	77	70	78	73
4	Marlette Lake-Frontal Lake Tahoe	91	91	91	50
43	Lower South Fork American River	122,958	122,565	121,827	119,764
29	Wolf Creek	239,771	251,338	248,910	247,216
30	Middle Bear River	257,675	272,725	262,192	272,599
10	Upper Truckee River-Frontal Lake Tahoe	303,398	301,244	288,560	297,405
11	General Creek-Frontal Lake Tahoe	307,778	303,199	278,516	291,404
25	Deer Creek	367,505	366,375	347,081	311,185
42	Weber Creek	395,042	380,576	384,108	394,701
37	Silver Fork American River	514,473	509,841	459,657	464,279
40	Rock Creek	555,584	553,325	442,152	430,417
13	Prosser Creek-Truckee River	584,348	574,683	517,041	522,625
3	Third Creek-Frontal Lake Tahoe	594,100	649,223	609,346	580,267
28	Upper Bear River	674,778	675,401	604,505	608,061
41	Middle South Fork American River	719,425	719,214	633,982	631,117
36	Lower North Fork American River	739,802	749,642	554,215	533,730
38	Silver Creek	778,278	773,800	648,146	658,256
26	Dry Creek	1,003,635	947,984	949,264	893,010
27	Yuba River	1,313,105	1,254,960	1,128,531	1,140,504
12	Little Truckee River	1,194,978	1,207,951	1,130,321	1,151,060
39	Upper South Fork American River	1,285,564	1,296,605	1,193,203	1,179,998
33	Upper Middle Fork American River	1,584,582	1,568,486	1,526,463	1,524,845
34	North Fork Middle Fork American River	1,584,892	1,568,765	1,486,896	1,496,077
20	Middle North Yuba River	1,637,867	1,641,287	1,569,341	1,558,579
35	Lower Middle Fork American River	1,701,653	1,827,875	1,541,955	2,418,818
23	Upper South Yuba River	1,683,585	1,629,802	1,523,527	1,532,862
18	Downie River	1,898,927	1,907,818	1,856,365	1,849,056
24	Lower South Yuba River	1,995,586	2,008,754	1,869,405	1,879,016
19	Upper North Yuba River	2,508,691	2,503,157	2,192,056	2,146,694
22	Middle Yuba River	2,767,453	2,774,349	2,508,710	2,513,183
32	Rubicon River	3,069,495	3,072,550	2,885,626	2,890,410
21	Lower North Yuba River	3,388,507	3,334,262	3,003,335	3,021,119
31	Upper North Fork American River	3,581,959	3,583,637	3,219,344	3,273,063

Additional results for sediment retention.

Table C2.5. Sediment export differences between 2040 scenarios and replicates and 2020 summed by associated dam watersheds.

2040 Scenarios & Replicates

Watershed ID	Subwatershed Name	Sediment Export Difference Scenario 1 High (tons)	Sediment Export Difference Scenario 1 Low (tons)	Sediment Export Difference Scenario 6 High (tons)	Sediment Export Difference Scenario 6 Low (tons)
20	French Lake	17,249	16,992	15,260	16,138
5	Loon Lake	17,866	17,919	17,066	17,050
18	Independence	19,396	19,432	19,153	19,107
8	Sugar Pine	24,361	24,450	20,563	21,666
17	Donner Lake	28,819	29,174	23,620	22,222
7	Lake Valley	34,301	34,387	28,125	27,988
6	Ice House	51,678	52,437	33,571	33,203
2	Mark Edson	55,243	54,894	46,221	46,455
10	Caples Lake	57,114	56,963	56,684	57,200
14	Lake Fordyce	154,158	154,201	139,261	138,119
11	Bowman	162,552	162,559	149,433	143,465
3	Union Valley	170,975	170,794	153,196	150,968
15	Scotts Flat	180,253	180,390	166,381	167,164
16	Jackson Meadows	221,562	220,787	193,658	195,865
19	L. L. Anderson	427,751	432,285	398,789	412,407
13	Lake Spaulding	433,629	436,057	408,006	415,389
1	Rollins	680,713	679,980	628,131	640,066
4	Lower Hell Hole	895,709	907,004	846,882	849,949
9	Slab Creek	2,775,493	2,761,269	2,442,587	2,502,658
12	New Bullards Bar	9,490,783	9,477,890	8,829,357	8,910,194

Table C2.6. Sediment export differences between 2060 scenarios and replicates and 2020 summed by associated dam watersheds.

2060 Scenarios & Replicates

Watershed ID	Subwatershed Name	Sediment Export Difference Scenario 1 High (tons)	Sediment Export Difference Scenario 1 Low (tons)	Sediment Export Difference Scenario 6 High (tons)	Sediment Export Difference Scenario 6 Low (tons)
20	French Lake	16,804	15,631	14,663	14,694
5	Loon Lake	17,132	16,258	16,180	15,956
18	Independence	18,580	18,739	16,856	18,596
8	Sugar Pine	24,299	24,187	18,145	18,846
17	Donner Lake	27,123	26,697	21,706	22,970
7	Lake Valley	31,881	32,873	24,856	26,212
6	Ice House	50,588	48,865	30,473	30,930
2	Mark Edson	51,474	52,696	43,063	42,671
10	Caples Lake	55,986	55,236	56,244	56,081
14	Lake Fordyce	149,129	150,237	131,288	134,163
11	Bowman	153,477	153,894	131,738	141,749
3	Union Valley	164,821	164,239	142,486	142,012
15	Scotts Flat	180,229	179,953	161,732	159,823
16	Jackson Meadows	209,026	207,739	174,523	178,934
19	L. L. Anderson	397,728	396,707	368,416	372,116
13	Lake Spaulding	410,291	396,721	386,750	378,893
1	Rollins	674,778	675,401	604,505	608,061
4	Lower Hell Hole	856,591	853,901	785,031	816,526
9	Slab Creek	2,642,197	2,647,612	2,329,154	2,333,867
12	New Bullards Bar	9,384,530	9,335,219	8,584,406	8,536,904

Appendix D: GIS Results

Additional results for habitat quality using ArcGIS Pro for analysis and visualization.

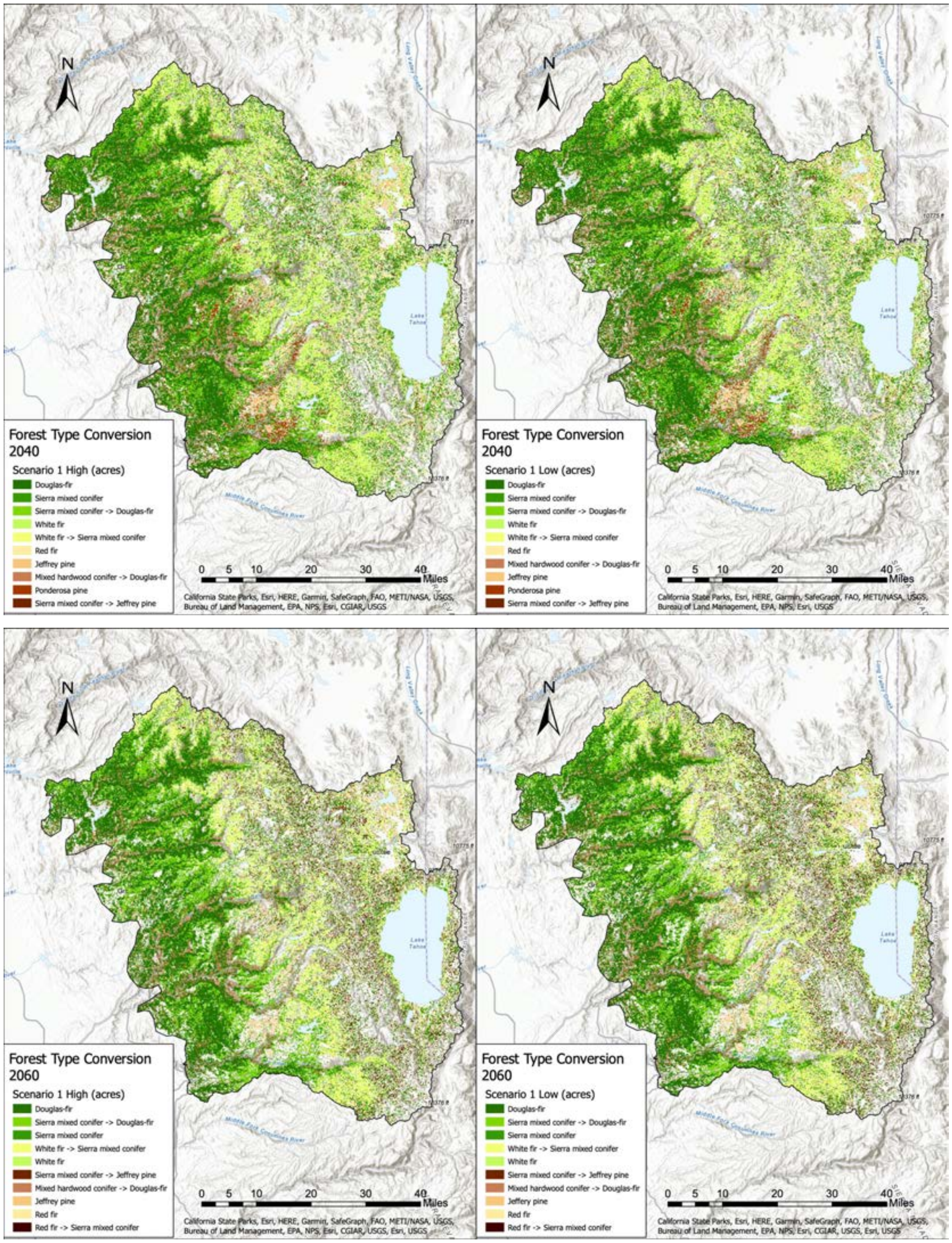


Figure D1. Top ten most significant forest conversions by acreage for 2040 (top) and 2060 (bottom) scenario 1 high (left) and low (right). Legend symbology is based on the different types of forest conversions listed from the greatest change (in acreage) at the top to least greatest change (in acreage) at the bottom on the legend. Symbology is consistent throughout the years, scenarios, and forest conversion types (i.e. Dark green is always Douglas fir conversion; dark red is always Red fir -> Sierra mixed conifer conversion).

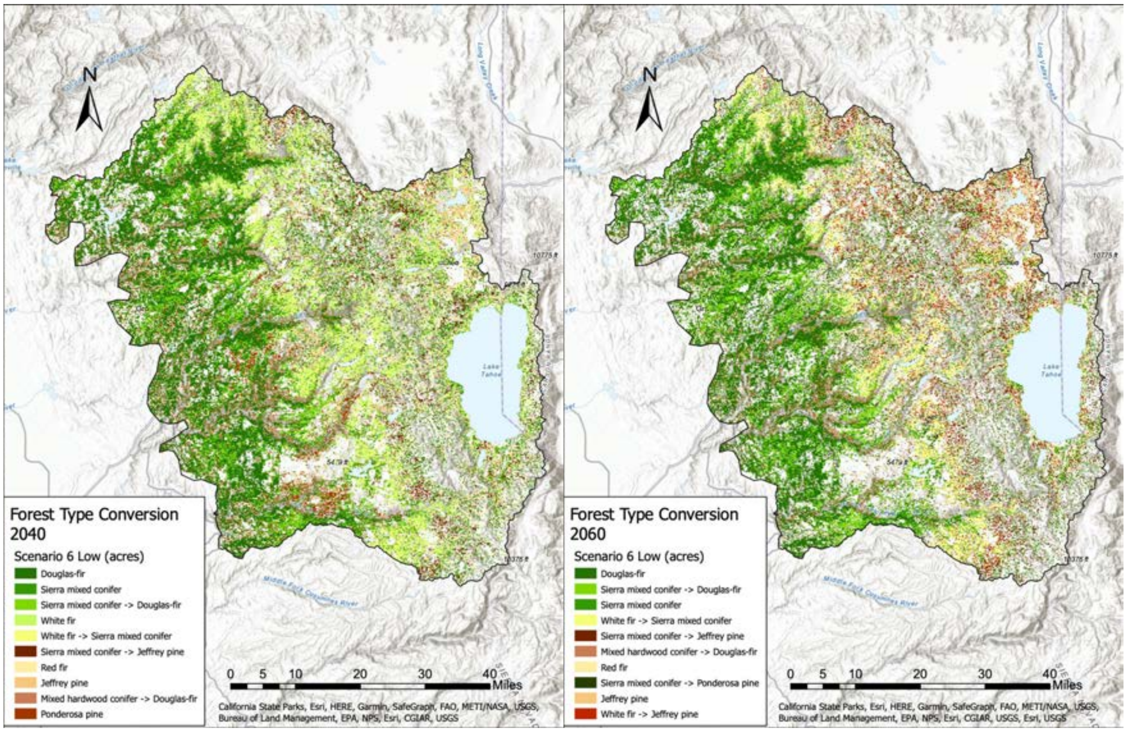


Figure D2. Top ten most significant forest conversions by acreage for 2040 (top) and 2060 (bottom) scenario 6 high (left) and low (right). Legend symbology is based on the different types of forest conversions listed from the greatest change (in acreage) at the top to least greatest change (in acreage) at the bottom on the legend. Symbology is consistent throughout the years, scenarios, and forest conversion types (i.e. Dark green is always Douglas fir conversion; dark red is always Red fir -> Sierra mixed conifer conversion).

Additional tabular results for habitat quality using R Studio for analysis looking at the net change and percent change of forest type conversions for each year and scenario.

Table D1. Net change, Total Area, and Percent change of each forest type for 2040 scenario 1 high (top) and low (bottom). Negative net change values equate to loss while positive values equate to gain. "Increase from 0" represents forest types that were not present in 2020 but are present in 2040.

2040 Scenario 1 High

Forest Type	Net Change 2020-2040 (acres)	Total Area 2040 (acres)	Percent Change 2020-2040
Aspen	96.07	96.07	Increase from 0
Chapparal	-8.01	0.00	-100.00%
Douglas-fir	289,568.24	735,273.40	64.97%
Jeffrey pine	55,002.59	157,914.29	53.45%
Juniper	-1,665.29	3,490.70	-32.30%
Lodgepole pine	2,161.67	2,553.98	551.02%
Mixed hardwood conifer	-98,011.90	15,459.97	-86.38%
Montane hardwood	-21,272.47	9,855.63	-68.34%
Montane riparian	-232.18	120.09	-65.91%
Ponderosa pine	35,107.19	116,938.56	42.90%
Red fir	3,274.54	140,292.64	2.39%
Sierra high elevation mixed conifer	-27,341.17	58,165.04	-31.98%
Sierra mixed conifer	-84,201.21	572,419.28	-12.82%
White fir	-152,478.08	207,993.07	-42.30%

2040 Scenario 1 Low

Forest Type	Net Change 2020-2040 (acres)	Total Area 2040 (acres)	Percent Change 2020-2040
Aspen	96.07	96.07	Increase from 0
Chapparal	-8.01	0.00	-100.00%
Douglas-fir	290,320.82	735,881.87	65.16%
Jeffrey pine	47,412.72	150,468.52	46.01%
Juniper	-1,777.38	3,418.65	-34.21%
Lodgepole pine	2,329.80	2,730.11	582.00%
Mixed hardwood conifer	-97,875.80	15,628.10	-86.23%
Montane hardwood	-21,352.54	9,679.50	-68.81%
Montane riparian	-264.20	80.06	-76.74%
Ponderosa pine	32,200.94	113,992.28	39.37%
Red fir	7,661.93	144,888.20	5.58%
Sierra high elevation mixed conifer	-27,397.22	58,285.14	-31.98%
Sierra mixed conifer	-87,459.73	569,216.80	-13.32%
White fir	-143,887.43	216,231.45	-39.96%

Table D2. Net change, Total Area, and Percent change of each forest type for 2060 scenario 1 low. Negative net change values equate to loss while positive values equate to gain. "Increase from 0" represents forest types that were not present in 2020 but are present in 2060.

2060 Scenario 1 Low

Forest Type	Net Change 2020-2060 (acres)	Total Area 2060 (acres)	Percent Change 2020-2060
Aspen	320.25	320.25	Increase from 0
Douglas-fir	383,288.82	828,665.72	86.06%
Jeffrey pine	123,319.50	220,955.11	126.31%
Juniper	6,444.99	11,280.74	133.28%
Lodgepole pine	10,928.46	11,288.74	3033.33%
Mixed hardwood conifer	-97,379.41	15,155.74	-86.53%
Montane hardwood	-15,572.06	14,419.17	-51.92%
Montane riparian	-72.06	248.19	-22.50%
Ponderosa pine	32,409.10	112,238.92	40.60%
Red fir	-37,693.19	88,292.37	-29.92%
Sierra high elevation mixed conifer	-34,602.80	46,243.81	-42.80%
Sierra mixed conifer	-162,301.69	481,244.68	-25.22%
White fir	-209,089.92	132,838.87	-61.15%

2060 Scenario 1 High

Forest Type	Net Change 2020-2060 (acres)	Total Area 2060 (acres)	Percent Change 2020-2060
Aspen	344.27	344.27	Increase from 0
Chapparal	32.02	40.03	400.00%
Douglas-fir	384,545.79	829,882.66	86.35%
Jeffrey pine	107,066.91	204,366.26	110.04%
Juniper	7,021.44	11,873.19	144.72%
Lodgepole pine	12,401.60	12,761.88	3442.22%
Mixed hardwood conifer	-97,787.73	14,715.40	-86.92%
Montane hardwood	-15,956.36	13,786.68	-53.65%
Montane riparian	-96.07	232.18	-29.27%
Ponderosa pine	33,025.58	112,735.30	41.43%
Red fir	-31,464.37	95,570.01	-24.77%
Sierra high elevation mixed conifer	-32,281.00	48,965.92	-39.73%
Sierra mixed conifer	-163,374.52	480,844.37	-25.36%
White fir	-203,477.57	137,474.46	-59.68%

Table D3. Net change, Total Area, and Percent change of each forest type for 2040 scenario 6 high (top) and low (bottom). Negative net change values equate to loss while positive values equate to gain. "Increase from 0" represents forest types that were not present in 2020 but are present in 2040.

2040 Scenario 6 High

Forest Type	Net Change 2020-2040 (acres)	Total Area 2040 (acres)	Percent Change 2020-2040
Aspen	1,136.88	1,136.88	Increase from 0
Chapparal	8.01	8.01	Increase from 0
Douglas-fir	209,418.17	637,037.32	48.97%
Jeffrey pine	146,041.09	237,103.61	160.37%
Juniper	-2,145.66	2,810.18	-43.30%
Lodgepole pine	7,005.43	7,389.72	1822.92%
Mixed hardwood conifer	-83,136.38	29,382.75	-73.89%
Montane hardwood	-4,811.73	25,860.03	-15.69%
Montane riparian	96.07	432.33	28.57%
Ponderosa pine	112,351.00	189,250.56	146.10%
Red fir	-18,910.64	107,122.96	-15.00%
Sierra high elevation mixed conifer	-35,563.54	48,253.37	-42.43%
Sierra mixed conifer	-158,883.04	451,589.71	-26.03%
White fir	-172,605.67	143,799.36	-54.55%

2040 Scenario 6 Low

Forest Type	Net Change 2020-2040 (acres)	Total Area 2040 (acres)	Percent Change 2020-2040
Aspen	1,345.04	1,345.04	Increase from 0
Douglas-fir	199,898.80	628,526.73	46.64%
Jeffrey pine	143,839.39	235,262.19	157.33%
Juniper	-2,177.69	2,826.19	-43.52%
Lodgepole pine	5,740.45	6,132.75	1463.27%
Mixed hardwood conifer	-83,576.72	29,390.76	-73.98%
Montane hardwood	-6,797.26	24,314.83	-21.85%
Montane riparian	-32.02	312.24	-9.30%
Ponderosa pine	117,515.00	194,814.86	152.02%
Red fir	-15,540.03	111,374.25	-12.24%
Sierra high elevation mixed conifer	-37,060.70	47,036.43	-44.07%
Sierra mixed conifer	-153,951.22	459,139.56	-25.11%
White fir	-169,203.03	149,996.16	-53.01%

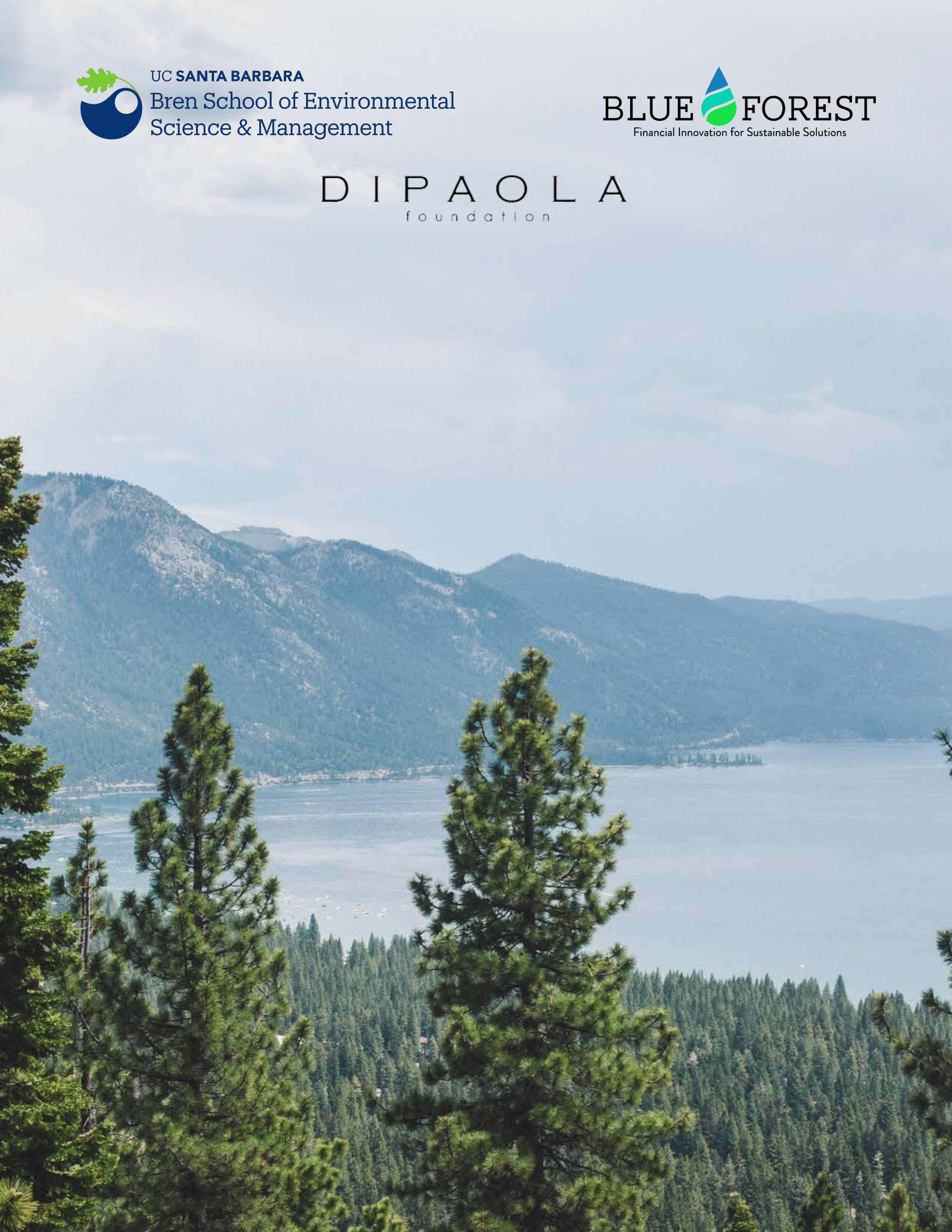
Table D4. Net change, Total Area, and Percent change of each forest type for 2060 scenario 6 low. Negative net change values equate to loss while positive values equate to gain. "Increase from 0" represents forest types that did not occur in 2020 but are present in 2060.

2060 Scenario 6 High

Forest Type	Net Change 2020-2060 (acres)	Total Area 2060 (acres)	Percent Change 2020-2060
Aspen	1,729.34	1,729.34	Increase from 0
Chapparal	40.03	40.03	Increase from 0
Douglas-fir	271,586.32	691,143.22	64.73%
Jeffrey pine	189,018.38	273,924.13	222.62%
Juniper	2,409.87	6,965.39	52.90%
Lodgepole pine	22,409.35	22,769.63	6220.00%
Mixed hardwood conifer	-82,503.89	28,229.86	-74.51%
Montane hardwood	11,729.08	40,887.66	40.23%
Montane riparian	624.48	936.73	200.00%
Ponderosa pine	107,851.52	181,620.65	146.20%
Red fir	-52,536.68	60,895.16	-46.32%
Sierra high elevation mixed conifer	-37,821.29	40,463.33	-48.31%
Sierra mixed conifer	-226,951.75	358,149.35	-38.79%
White fir	-207,584.75	87,900.07	-70.25%

2060 Scenario 6 Low

Forest Type	Net Change 2020-2060 (acres)	Total Area 2060 (acres)	Percent Change 2020-2060
Aspen	1,601.24	1,601.24	Increase from 0
Chapparal	40.03	40.03	Increase from 0
Douglas-fir	269,824.95	687,204.17	64.65%
Jeffrey pine	176,408.61	261,474.49	207.38%
Juniper	1,953.51	6,428.98	43.65%
Lodgepole pine	22,585.49	22,937.76	6411.36%
Mixed hardwood conifer	-83,680.80	26,668.65	-75.83%
Montane hardwood	10,023.76	39,118.29	34.45%
Montane riparian	544.42	824.64	194.29%
Ponderosa pine	106,154.21	179,106.70	145.51%
Red fir	-45,923.56	68,605.13	-40.10%
Sierra high elevation mixed conifer	-36,316.12	43,097.37	-45.73%
Sierra mixed conifer	-222,308.16	363,249.30	-37.97%
White fir	-200,907.58	95,297.80	-67.83%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