“Mitigating wildfire hazard in the redwoods: effectiveness and tradeoffs of fuels treatments”

Scope of Work

1. Problem statement

Deadly wildfires ravaging California are prompting timberland owners to seek guidance on mitigating risks (CA BoF 2018). At present, little guidance is available for the redwood region where severe wildfire has been uncommon…until recently! (Goss et al. 2020). Fire weather is becoming more extreme (Stephens et al. 2014). Higher fire severity may also be due to climate change effects including declining coastal fog and multiyear droughts (Thorne et al. 2017, 2018) that slow the decomposition of hazardous surface fuels that drive fire behavior (Davies et al. 2016). We cannot change the weather, so we must focus on better managing timberlands to create forest conditions where future fires are less destructive (FMTF 2021). Management approaches that need to be tested and compared in redwood forests include harvesting to reduce stand density followed by application of fuels treatments such as lop and scatter or mastication (Jain et al. 2014) and/or prescribed burning (York et al. 2021).

Some coastal forests that regenerated after harvesting long ago are becoming progressively denser and need management to promote forest health, reduce hazardous fuel loads, and to space trees further apart before the next wildfire (FRAP 2017, Forest Climate Action Team 2018). Other coastal forests are actively managed for timber and other objectives, but without scientific knowledge of how prescription choices could alter fire severity. Research is needed to answer the burning question: “*In redwood forests, how does fire behave under different approaches to silviculture combined with different fuels treatments? and how does fire behavior change over time since treatment?*”. Such information would guide redwood region landowners and managers seeking to mitigate the risk of high-severity wildfire by implementing combinations of timber harvest or precommercial thinning, and/or fuels treatments that are suitable for their particular conditions and objectives (Forest Climate Action Team 2018).

Field experiments must be established to test and compare alternate forest management treatments side-by-side, but until future wildfires burn through these experiments and show real fire effects (North and Hurteau 2011, Lydersen et al. 2017), the best available approach is to simulate first-order fire effects in different stand structures under different fire weather scenarios (Reinhardt et al. 2001, Stephens et al. 2012).

To answer our research question about fire behavior and management, we will conduct research to test the following hypotheses:

Hypothesis 1: Fuel load (in terms of tons/acre and fuelbed height) will rank as follows immediately after different silvicultural prescriptions: higher retention density < lower retention density, and after different fuels treatments: biomass removal < Rx fire with prep < Rx fire < mastication < lop & scatter/crush < no treatment.

Hypothesis 2: Modeled fire severity (in terms of basal area mortality (% and ft^2/ac) and indices of crowning and torching (miles/hour windspeed)) will differ significantly among combinations of silviculture × fuels treatments, and will worsen over time since treatment due to understory development (York et al. 2021).

Hypothesis 3: Over 10 years following selection harvest, regenerating trees and understory vegetation exhibit slower development beneath dense dispersed overstory, intermediate development under aggregated overstory or a light dispersed overstory, and faster development in group selection openings (all trees removed), in terms of tree size, vegetation cover, and fuel load.

Hypothesis 4: Precommercial thinning in 10-year-old regeneration after four different selection harvest treatments leads to different fuel load and modeled fire severity in each treatment, ranking from lowest to highest: dispersed high-density retention < aggregated high-density retention < dispersed low-density retention < group selection openings.

2. Relevance to Research Program priority topics

Our research into the combined effects of silviculture × fuels treatments on fire severity directly addresses two of the six ‘priority research topics’, specifically: “…*prediction of threats such as … wildfire and associated impacts to forest health*…” (Topic no.1), and “*Implementation, effectiveness, impacts, and tradeoffs of alternative management strategies to reduce wildfire risk*,…” (Topic no. 2). We tackle these two priority topics using a combination of large-scale, long-term field experimentation and fire behavior modeling based on field data collected from our experiments stretching across the largest demonstration state forest in California: the 50,000-acre Jackson Demonstration State Forest (JDSF) in Mendocino County.

3. Methods

Our research testing silviculture × fuels treatment effects on fire severity has two parts:
1. Implement a new manipulative experiment replicated at multiple sites across JDSF, and
2. Re-measure and treat fuels in existing experiment on JDSF 10 years after harvest.

Part 1. New experiment: comparing post-treatment fuels and fire effects
Rigorous manipulative field experimentation will be replicated no less than six times on JDSF to generate valid results with a broad range of applicability. JDSF has identified 14 active and planned timber harvest plans (THP) which fit the research goals and timeframe, giving ample replacement sites in case of operational delays (Figure 1).

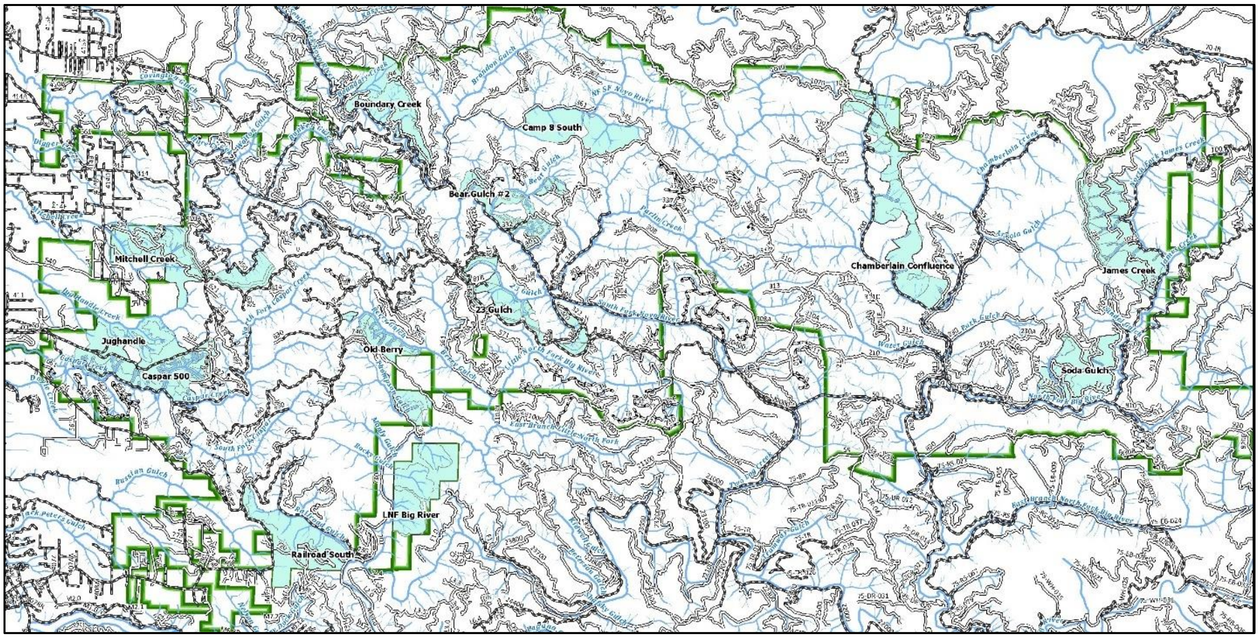

Figure 1: *Map of JDSF (50,000 acres) showing 14 candidate study areas.*

At each selected site, a relatively uniform area will be selected as a single experimental replicate where all reasonable/permissible fuels treatments are implemented beside/near each other in 10-acre blocks (Figure 2). Licensed JDSF foresters will determine the silvicultural prescription and harvest system employed in each replicate (described in THP). JDSF will also provide leadership in fuels treatment design details, contract language, implementation, and supervision. Prescribed fire will be implemented as a collaboration between JDSF and the research team. Surrounding the 60 acres of fuels treatment experiment at each site, JDSF will implement the most practicable fuels treatment to the remaining THP area.

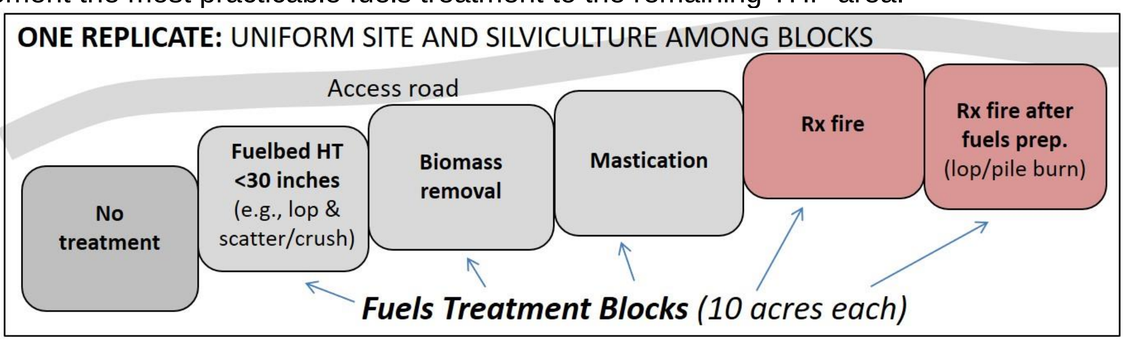

Figure 2: *Schematic map of fuels treatments randomly assigned to blocks at one site on JDSF.*

<u>Fieldwork</u>: the research team will identify treatment blocks, and collect pre- and post-treatment data from forest inventory plots with regeneration & vegetation subplots, and fuels transects in each block, as follows:

- Survey GPS & flag treatment block boundaries (10 acres per block)
  - Locate treatment blocks adjacent to access roads to facilitate demonstration/tours
  - Randomly assign one treatment to each block
- Measure existing/new inventory plots near center of each treatment block

    - 10% sampling intensity (i.e., 1 × 1/10th-acre plot per acre = 10 plots per treatment block)
    - Measure tree diameter at 4.5 ft breast height (DBH), tree height (HT), and live crown base height (LCBH; height of lowest live branch) data needed for modeling tree growth and fire behavior
    - Subsample regeneration and vegetation in 1/100th-acre subplot at plot center (or north radius to avoid trampling)
- Assess fuel load per Brown's Inventory (Brown 1974) with enhancements
    - Sample at statistically appropriate intensity (Brown 1974).
    - Monument fuels transects for future re-measurements using flagged rebar driven flush with ground at each end of transect, and GPS'd
    - 360-degree photos for comparison as 'remote sensing' of fuels, and future virtual tours
- Conduct and monitor prescribed burning
    - Coordinate with CAL FIRE prescribed burn personnel to develop a burn prescription that meets an objective of >50% surface fuel consumption while limiting canopy damage to generally less than 50% crown volume scorch.
    - Fire and fire effects monitoring will include:
        - Basic weather data under which burns are conducted (temperature, relative humidity, 10-hour fuel moisture content)
        - Re-measurement of fuel transects will provide a measurement of fuel consumption
        - Percent crown volume scorch and 1-yr and 2-yr post burn tree mortality will be assessed, post burn

Data analysis: research team analyzes fuel load and stand data to reveal how these differ among treatment combinations, and to identify influential variables. The replicated randomized incomplete block split-plot experimental design is designed specifically to detect fine differences among fuels treatments via mixed-effects analysis that accounts for nesting of fuels treatments within silviculture treatment plots (Aastveit et al. 2009).

Fire behavior modeling: research team will input field data into fire effects models to predict fire severity under different weather and stand conditions to develop a matrix of outcomes for:

- Current post-treatment conditions in each treatment
- Future conditions: temporal change in fire severity
    - Simulate tree growth in each inventory plot, then enter future tree data into fire models to predict fire severity over time-since-treatment (these simulations represent the best available information until we collect fuels data in each treatment block in future years: year 2, 5, 10, 15, 20 i.e., beyond the scope of this proposal)

Part 2. Tending in existing experiment: fuels and fire effects 10 years after selection harvests
A selection silviculture experiment was established 10 years ago by the research team (Figure 3). The same four treatments were replicated at four sites across JDSF. The most accessible site is visited regularly by forestry students and professionals (Figure 4). Graduate students

have conducted rigorous thesis research into tree regeneration and growth (Muma 2019, Schneider 2019). Outreach has been done locally and nationally (Berrill 2018, 2919) and early results published in a top forestry journal (Berrill et al. 2018).

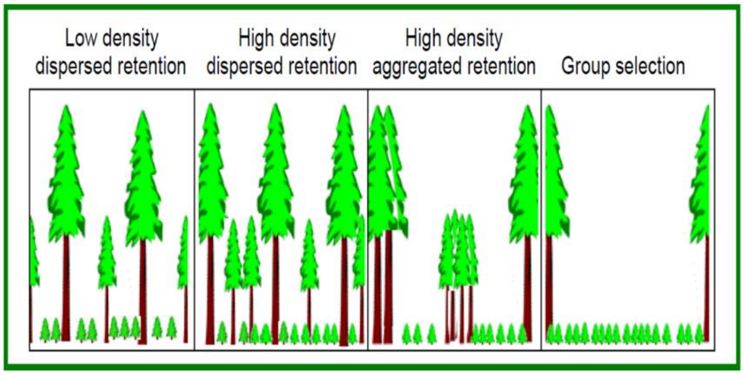

Figure 3: *Schematic diagram of four alternative continuous cover treatments tested side-by-side in 5-acre blocks at each experiment site (20 acres per site; 80 acres total across the 4 sites on JDSF).*

Figure 4: *JDSF Research and Demonstration Manager Lynn Webb and forestry students discuss future management of 6-yr-old understory shrubs & trees in group selection opening, including redwood clumps in rear left.*

The 10-year-old understory has attained canopy closure and become a potential ladder fuel hazard (Banerjee et al. 2020). Precommercial thinning (PCT) has been recommended by JDSF foresters using their standard prescription. However, PCT is uncommon in selection silviculture so we do not know how much surface fuel load will be created by PCT, or how quickly these so-called 'activity fuels' will decompose, nor do we have information to guide the choice of fuels treatment options. Therefore, we propose to assess fuel load under each selection treatment before and after PCT, with and without different fuels treatments applied to these activity fuels.

Fieldwork: the research team collects tree size data, understory vegetation cover and diversity, and fuel load before PCT, in winter 2021 at one site and winter 2022 at three sites (i.e., 10 years after selection harvest). Then, after contractors implement PCT at each site (supervised by JDSF), realistic fuels treatments are designed by JDSF and research team and implemented in one or more quarters of each plot, with fuel load re-assessed in each quarter. Example fuels treatments could be: pile and burn cut vegetation to reduce continuity of surface fuels; lop and scatter fuels to reduce fuelbed height and promote decomposition from ground contact; do nothing. Prescribed burning may be tested in one quarter and could be extended alongside each plot into the silviculture buffer as needed to increase the burn footprint and/or facilitate implementation.

- Tree measurements in ½-acre permanent plots:

    - DBH, HT, and LCBH of all tagged trees and the selected age-10 redwood and tanoak sprout clumps previously measured for height. Established protocols will be used to permanently designate and map post treatment residual trees.
- Fuel load:
    - Divide each square plot into quarters by installing a plot center post and bisecting the plot with four fuels transects extending from each corner towards plot center.
    - Assess fuel load before and after PCT and any associated fuels treatments. Extra transect length or extra transects will be added depending on fuel load, per Brown (1974)
- Understory vegetation assessment:
    - Vegetation plots will be assessed by quadrant with ocular percentage cover and dominant vegetation height by species.
- Prescribed burning: conduct burns and collect data using same method from Part 1 above.

Data analysis: research team analyzes fuel load and stand data to reveal how these differ among treatments, and to identify influential variables. Mixed-effects regression analysis accounts for nesting of fuels treatments within silviculture treatment plots.

Fire behavior modeling: the research team will input pre- and post-treatment field data into fire effects models to predict fire severity under different weather and stand conditions to develop a matrix of outcomes for:
- Current pre- and post-treatment conditions in each treatment, and
- Future conditions using growth model predictions of future stand conditions based on post-treatment data collected in each plot.

4. Workplan, including project tasks and deliverables

Project tasks (new silviculture × fuels treatment experiment):
- Survey GPS & flag treatment block boundaries; randomly assign treatments to each block
- Inventory stand: trees, vegetation, fuel load
- Community stakeholder consultation, invitations for engagement
- Implement fuels treatments in 10-acre blocks
- Re-assess fuel load and understory vegetation using monumented fuels transects
- Data analysis: fuel load and forest attributes compared among treatments
- Fire behavior modeling: present and future (using growth and yield model projections)
- Outreach activities including dissemination of results & final reporting

Project tasks (10-year assessment and tending of existing experiment):
- Pre-treatment assessment of stand conditions: measure trees, vegetation, fuel load
- Implement PCT, followed by fuels treatments
- Post-treatment stand conditions: measure trees, vegetation, fuel load
- Data analysis: fuel load and forest attributes compared among treatments
- Fire behavior modeling: present and future (using growth and yield model projections)
- Outreach activities including dissemination of results & final reporting

Deliverables:

- ✓ New long-term field experiment established
- ✓ Datasets from new and existing experiment stored at JDSF
- ✓ Peer-reviewed publications × 2 (fuel load & modeled fire; prescribed burning)
- ✓ Outreach: brochures for visitors; signage; workshop (see below)
- ✓ Final project report & final project data to CAL FIRE

5. Knowledge transfer and outreach plan

Our findings about relative effectiveness of each type of fuels treatment will be relevant to future fuels management projects applied in redwood forests experiencing the coastal climate of California's north coast.

Knowledge transfer: the new silviculture × fuels treatment experiment generates data regularly into the future, but within the project period of performance we will publish a masters of forestry (MF) thesis on prescribed burning in the redwoods, a masters (MS) thesis on fuel load and fire effects modeling under different silviculture and fuels treatments, and peer-reviewed publication on (i) post-treatment fuel load, and (ii) the fire effects modeling results.

Demonstration & Outreach:

- Tribal engagement: Coyote Valley Band of Pomo & Sherwood Valley Tribe
    - Consultation with tribes and invitation to participate in burning
    - Expose tribal youth to forest management and burning practices
- Roadside interpretive signs for each treatment block at sites with public use
- Brochure for visitors and JDSF website with treatment and research summary
- Presentations at national/regional and local conferences
    - Society for American Foresters national or CA state annual meeting
    - CA Forest Pest Council summer field tour or winter meeting
- UC Cooperative Extension 'fire and fuels' workshop for landowners

6. Relevance to state and local plans and strategies

Risk of wildfire is immediately, directly reduced by our experimental harvest and fuels treatments over multiple sites. Stand density will be reduced which should mitigate risk of extreme fire behavior. Smaller trees (ladder fuels) will be cut or damaged during harvesting and then treated as harvest residues. Harvest residues receive a variety of fuels treatments soon after harvest: lop and scatter/crush, mastication, complete biomass removal. These treatments modify the fuel bed by reducing its height and the aeration of surface fuels which is expected to reduce fire line intensity. We will also use prescribed fire to reduce hazardous fuel load. The proposed treatments are compatible with local fire and management plans for Mendocino County (Mendocino Unit) where the experiment will be conducted.

Local Fire Plan for Mendocino Experiment Sites

The California Department of Forestry and Fire Protection's Mendocino Unit consists of 2,361,560 acres. CAL FIRE provides direct protection for 2,244,450 acres, 28,145 of which are in southern Trinity County. With the exception of the four incorporated cities of Ukiah, Fort Bragg, Willits, Point Arena, and small areas of Local Responsibility Area (LRA) lands within Mendocino County, CAL FIRE maintains statutory responsibility for all wildland fires. Of the total county population, approximately 67% live on State Responsibility Area (SRA) lands. The most recent update (2014) of the Unit Strategic Fire Plan Mendocino Unit states: “The overall goal of the Mendocino Fire Plan is to reduce total costs and losses from wildland fires within the Unit by protecting assets at risk through focused pre-fire management prescriptions and increased initial attack success. To make the Unit fire plan a success, several key objectives to achieve should be strived for during implementation of the plan, including;

- Collection and analysis of data from a variety of resources to evaluate potential projects and determine the levels of benefits provided to communities and environment within the Unit…”

Other Plans for Mendocino Experiment Sites

The Jackson Demonstration State Forest Management Plan of 2016 guides the management of the forest and implementation of the THPs which will include the proposed experimental areas. The installation of the new experiment and its objectives (i.e., research and demonstration), and the proposed treatments in the existing selection silviculture experiment, are consistent with and further the goals of the Management Plan. It will complement and incorporate goals of the 2018 Jackson Demonstration State Forest Fire Protection and Pre-Attack plan.

The 2005 Mendocino County Community Wildfire Protection Plan, authored by Mendocino County Fire Chiefs’ Association & California Department of Forestry and Fire Protection Mendocino Unit describes the goals and mission of the Mendocino County Fire Safe Council: “The Mendocino County Fire Safe Council is a coalition of individuals, businesses, and public and private agencies who share the goal of preventing loss of life, destruction of property, and damage to the environment caused by wildfire. The formal goals of the Council are:

- Work to minimize losses to values at stake, which include but are not limited to human lives, homes, animals, and natural resources;
- Educate residents, agencies, and other stakeholders about the nature and impacts of wildfire, fire prevention strategies, and effective preparedness in the event that wildfire occurs;
- Secure and utilize funding to assist residents in education, outreach, community projects, and other activities that further the mission and objectives of the Council;
- Act as an advocate for the people of Mendocino County in the area of fire prevention.”

7. Relevance to state priority landscapes and projects

High-severity wildfires have direct and indirect impacts on ecosystem services, local communities, and California’s economy. In terms of FRAP ‘Priority Landscapes’, our study areas are rated 3/5 or 4/5 indicating medium-to-high wildfire risk to ecosystem services (Figure 5A). Parts of our western-most study sites are rated 4/5 or 5/5 indicating very high wildfire risk to communities (Figure 5B). Stand-replacing wildfire can also have economic impacts if potential harvest volume is lost or downgraded. Redwood forests cover 1.3 million acres across 12 Californian counties, from Del Norte to Monterey County (Stewart 2007). Redwood represents around 15-20% of California’s total timber harvest volume (McIver et al. 2015). Additionally, redwood logs are 2-3 times more valuable than most commercial timber species (T&TV 2019). Therefore, any improvement in forest management guided by our research results and recommendations for fire risk mitigation across the redwood region will bring important benefits (or avoided losses). Similarly, our project addresses the three stated primary criteria for project review by the Forest Management Task Force’s Northern Regional Prioritization Group: “supports fire resistant communities; resource protection & enhancement; sustain economic development” (July 11, 2019 meeting notes; https://fmtf.fire.ca.gov/regional-prioritization-groups/northern/).

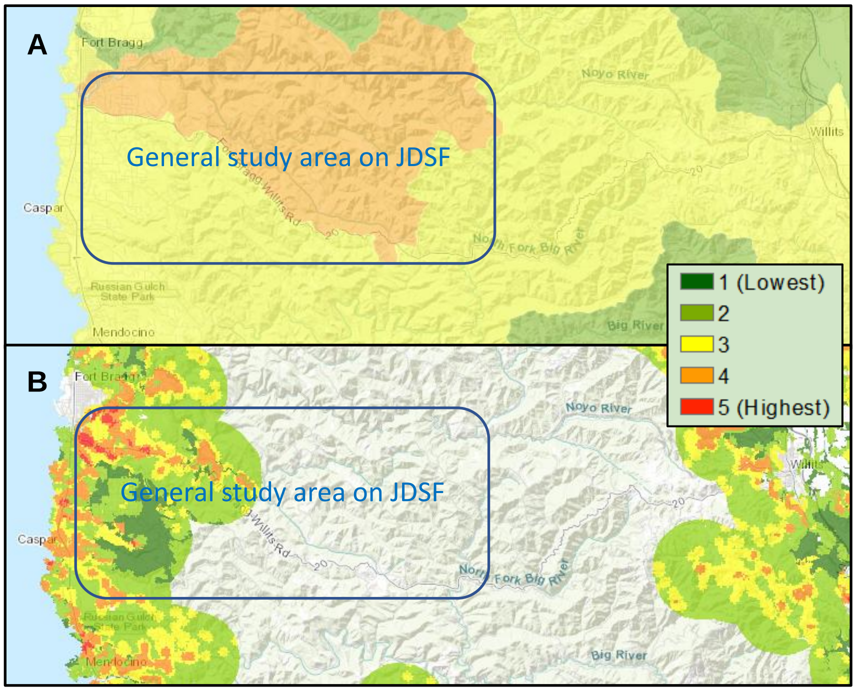

Figure 5: *Priority landscapes developed by FRAP, ranking 1-5 for (**A**) wildfire risk to ecosystem services, and (**B**) wildfire risk to communities.*

8. Description of greenhouse gas benefits

The primary greenhouse gas (GHG) reduction benefit comes from avoidance of emissions from future catastrophic (high severity) wildfires. This benefit will be estimated in terms of percent of total standing wood volume per acre not killed by wildfire across the project area, subtracted from percent total volume killed under the do-nothing control treatment. The mortality will be predicted using a fire effects model based on tree attributes and volume per acre predicted each decade using a ARB-approved growth and yield model.

The secondary GHG reduction benefit will come from improved forest management. Specifically, we will implement silvicultural prescriptions now and repeatedly into the future that will progressively convert the majority of each study area into more productive and valuable conifer-dominated forests (Berrill and Han 2017). Long-lived harvested wood products will be included in the calculations to more accurately reflect an important GHG reduction benefit of active management: the sequestration and storage of carbon in live trees and harvested wood (Berrill and Boston 2019).

Permanent monitoring installations at each site will allow for future re-measurement and validation or refinement of the growth and yield model predictions of wood volumes and carbon over the 100-year assessment period. This modeling will be a transparent and repeatable process using commonly-used forestry and fire effects models such as FVS-FFE, FOFEM and/or FMA+ applied to real field data collected immediately after implementation of each experimental treatment at each site.

The Principal Investigator has modeled C for prior GGRF grants and teaches two forestry classes where students develop 100-year carbon modeling projects using two different ARB-approved growth & yield modeling systems.

9. Relevance to long-term forest management and project co-benefits

This research project applies various multiaged/uneven-aged forestry techniques that will enhance timber production and associated economic activity and employment over the long-term, and have co-benefits for the environment, forest science and the forestry profession. As time goes on, our new and existing experiments require regular, repeated partial harvesting which sustains local jobs and infrastructure, and results in a steadily increasing log supply as stand production, conifer dominance, and value is enhanced over time (Berrill and Han 2017). Timber production benefits the local populations in Mendocino County by providing jobs and revenues in these remote areas with high levels of poverty and unemployment. The entire project area and surrounding communities that house the workforce and processing infrastructure are all classified as AB 1550 Low-income Communities (https://ww3.arb.ca.gov/cc/capandtrade/auctionproceeds/communityinvestments.htm). This particular census tract #6045010300 has declining population (currently only 4,042) with increasing unemployment and poverty, where 37% of people are living below twice the federal poverty level; this is higher than 61% of the census tracts in California. The unemployment rate is higher than 71% of census tracts in California. The composite score for sensitive populations and socioeconomic factors in our project area and surrounding communities is 64 which is among the worst in California (Figure 6).

Forestry Outreach and Education

(i) Each 60-acre experimental site affords side-by-side comparison of fuels treatments, alongside the untreated “do nothing” area, conferring demonstration and outreach value for forest managers, stakeholders, neighbors, other visitors, and university field trips. Locating some sites near permanent roads will facilitate year-round access.

(ii) Connecting the Registered Professional Forester preparing the THP for each site with contractors, students, and researchers in a professional setting fosters mutual respect and understanding of management constraints and research.

(iii) Field work, research, and/or burning experience will be gained by students and professionals involved in the establishment and re-measurement of the experiments, and working alongside researchers from multiple institutions (HSU, UCB, UCCE).

(iv) The controlled, replicated experimental design affords statistically-rigorous analyses and high likelihood of peer-reviewed publication of results.

(v) Quantifying rates of carbon sequestration and risk of carbon loss from wildfire under each treatment combination will help forest owners and managers understand the tradeoffs and prescribe the appropriate combination of treatments for their ownership and management objectives.

(vi) Every prescription being tested will have different costs and outcomes but all prescriptions are operationally feasible and represent realistic options for enhancing forest productivity and health.

(vii) Once established, the experiment offers opportunities for research in other disciplines, such as tree physiology, forest health, and ecosystem services (e.g., wildlife usage, biodiversity).

(viii) After each re-measurement of trees, regeneration, and fuel load in each treatment block, the data can be used to validate ARB-approved forest growth models, fuel models, and fire behavior models. If necessary, the data can be used to re-parameterize these models, or develop the next generation of models that better predict forest growth, fire risk, and carbon sequestration in future projects prescribing uneven-aged management.

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