STATEWIDE METRICS (IN ALL REGIONAL RESOURCE KITS)
METRIC DICTIONARY

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INTRODUCTION

WHAT IS THE REGIONAL RESOURCE KIT EFFORT?

Reducing the risk of large, high intensity fire (and other mega-disturbances) through forest treatments has become a management imperative in California. A Strategy for Shared Stewardship (2018) and the USFS Wildfire Crisis Implementation Plan (2022) reinforce specific goals for pace and scale of strategic forest treatments over the next decade. Concurrently, the State of California has issued a new Wildfire and Forest Resilience Action Plan (2022), designed to strategically accelerate efforts to restore the health and resilience of California forests through a joint State of California - Forest Service framework to improve and enhance forest stewardship in California. The social incentives and the scientific knowledge to pursue meaningful restoration of forested landscapes in California are firmly established.

High quality geospatial data are an essential ingredient to address restoration/conservation of the broad suite of core socio-ecological values across landscapes, and to drive analytic tools for planning management investments. To support these initiatives an interagency team of scientists from the Forest Service/Pacific Southwest Research Station, California Natural Resources Agency/CALFIRE, and the University of California at Berkeley and University of California at Irvine collaborated on development of a comprehensive set of mapped data layers needed to accomplish large-scale landscape planning and restoration. Landscape level assessment using high quality data developed from ecological modeling techniques, informative analytical approaches and the resulting credible scientific outputs will be fundamental to inform and support large landscape restoration planning and execution.

The data layers included in this kit are meant to assist land managers in assessing their current landscape and plan for treatments to enhance resilience to human and natural disturbances. Thus, each layer represents what the interagency team believes are the most relevant and reliable geospatial data available at this time. Each layer has been examined by the team and is supported by published data and/or was developed using standard methods. The methods for developing each layer are documented in the metric dictionary; however, the accuracy of each layer has not been quantified. It is anticipated that all data layers will be updated and refined as methods and source data evolve and improve.

WHAT THIS DOCUMENT IS AND ITS INTENDED PURPOSE

ORGANIZATIONAL STRUCTURE

This document has been organized to reflect the “Framework for Resilience” as set forth by the Tahoe Central Sierra Initiative (Manley et al. 2020, 2022). The framework is comprised of ten “**Pillars**” which support the full array of landscape management objectives that are inherently interdependent. Each pillar represents the desired long-term, landscape-scale outcome to restoring resilience. They include ecological values, such as biodiversity, as well as societal benefits to communities, such as water security. Within each pillar are “**Elements**” which represent the primary processes and core functions of that pillar, such as focal species, water quality, or economic health. Finally, within each element are the individual “**Metrics**” which describe the characteristics of elements in quantitative or qualitative terms. Metrics are used to assess, plan for, measure, and monitor progress toward desired outcomes and greater resilience.

The framework pillars are:

- **Fire Dynamics**
- **Forest Resilience**
- **Biodiversity Conservation**
- **Wetland Integrity**
- **Water Security**
- **Carbon Sequestration**
- **Air Quality**
- **Economic Diversity**
- **Fire Adapted Communities**
- **Social & Cultural Well-Being**

It is important to understand that while pillars and elements are consistent across California, the metrics used by a group may vary from region to region based on ecological and social differences (for example forest types or economy), available data, and the user preferences. It is equally important to recognize that due to the interdependent nature of the framework, some metrics overlap into multiple elements/pillars however have only been addressed a single time within this document.

METRICS

The metrics are organized by the 10 pillars of resilience in the Framework for Resilience. Each pillar represents a resource outcome associated with resilient forest landscapes. There are 47 metrics within the Statewide Resource kit, those specifically covering the entire state. The Metrics describe the characteristics of the elements (key characteristics) of each pillar in quantitative or, in a few cases, qualitative terms. Metrics are used to assess current conditions, plan treatments, and monitor for, measure, and monitor progress toward desired outcomes and greater resilience. Metrics are selected to be informative, meaningful, and actionable to meet the needs of management.

The metrics included within individual Regional Resource Kits are divided into three "tiers." Among all these metrics, some are created and relevant statewide (those in this Statewide Resource Kit). Additional metrics are more suited to issues/conditions within a given region. The "Tiers" for metrics included in each RRK

Tier 1 - metrics that are a single, consistent data layer, developed statewide; they can also be clipped to the boundary of the Region so values within that Region are the only ones included for calculations or regional statistics. Example: Annual Burn Probability.

These are the only metrics included here.

For the individual Region Kits other metrics are included in tier 2 and tier 3 categories, as described here.

Tier 2 - metrics relevant to a single Region or relevant to multiple Regions but data layers differ among the Regions because of varied data availability (sources) across Regions. Example: California gnatcatcher habitat suitability.

Tier 3 - metrics are those that would be of interest to some land managers for specific applications but not included in the as a core metric in an RRK. Example: Distribution of the Quino checkerspot butterfly.

Within Tier 1, the data layers are available in two forms: 1) data values native to the metric (raw), and 2) translated data values. The raw data values are in the native units or categories of the metric. For example, the species richness map will show an estimated number of terrestrial vertebrate species per acre that can range from 0 to any number for each 30-m pixel (units = species/area). Some metrics are in relative units. For example, the mean percent departure from historical fire return interval (PFRID) map will have values that range from -100% to +100% departure. Other metrics are expressed as categorical variables. For example, the seral stage metric assigns each pixel as being early, middle, or late seral stage. If the user needs to summarize conditions across multiple metrics, metric values need to be standardized so they can be compared.

Standardizing metrics with different units into a representation of condition that puts all metrics on the same numerical scale is the purpose of the translated data. With such standardized data, users can use a tool such as Planscape to identify areas that are likely to benefit from some sort of action from those that are less likely. Thus, the translated data values represent each metric using a common unit of measure with the same range of values from -1 to +1 that represent values that are generally considered favorable (+1) and unfavorable (-1). In the case of species richness, higher species counts are considered more favorable and lower species counts are considered less favorable. In the case of PFRID, values within the historical fire return interval are considered favorable, and high departure from the historical fire return interval is considered less favorable. For seral stage, favorability is based on how close the current fraction of early seral forests is to historical range of variation. In all cases, more and less favorable conditions for each metric are represented by values that range from +1 (favorable) to -1 (unfavorable). With this standardization, multiple metrics can be evaluated together, including summarizing overall conditions at element and pillar levels to characterize socio-ecological resilience.

Some data layers within this kit contain null values. We point this out here so users of the data will be aware and take whatever measures appropriate as they use and analyze the data. For some raster datasets in the RRK, areas have been masked (blanked) out and have a cell value of NoData (also referred to as null, NaN or missing). We, as producers and users of the data, cannot ignore NoData or fill them with zeros, since zero is often a valid value for some datasets. Removing NoData cells is not an option, a raster is a continuous grid. For users of the data performing further analyses and combining or "stacking" rasters, these NoData cells will mask out all values in that location in the output. To avoid this issue, the user must create values for the cells before combining them (i.e. 999 or any numeric value that is not real and clearly out of the range of the other values). Reasons for masking (blanking) out cells in RRK data include:

- Cells are located in water bodies (e.g., lakes, reservoirs, or large rivers)
- Cells are located in urban areas
- Cells are located in areas used for irrigated agriculture
- Cells contain no information relevant to the dataset (e.g. for a streams data layer, areas outside of streams have NoData)
- Area (cells) subject to fire or other disturbance but the post disturbance condition or value is unknown. Intended Purpose

Landscape level assessments, using high-quality data combined with decision support tools to help evaluate alternative treatment strategies, are fundamental to inform and support large landscape restoration planning. These data have been assembled in one place to provide comprehensive access for land managers.

Through this “metric dictionary,” each metric has been defined to help end-users of the data (and for use with any decision support tools) to understand:

- Data vintage
- The definition meant by a given metric
- The expected use(s) of the metric
- The resolution of the developed data
- The data sources used to derive the metric
- The method of metric derivation
- The root file names

References have been included to help the reader understand potential methods for deriving metrics. It is our hope this information will help people make better use of all the assembled information and how it can best be used with various decision support tools. This dictionary will be updated periodically, as necessary.

Note that all metric data layers have been masked (i.e. blocked out) for open water (lakes, reservoirs) and a selected few have been masked for the urban and agricultural landscape (see the list of operational layers at the end of this document. This is done to avoid confusion with vegetation values coming from urban areas (e.g. city parks) or agricultural areas (e.g. irrigated farm land).

The statewide metrics (by Pillar) available in this Regional Resource Kit are listed below.

FIRE ADAPTED COMMUNITIES

Wildfires are a keystone disturbance process in western US forests. However, the capacity for humans to coexist in the wildland urban interface (WUI) requires different restoration strategies aimed at the protection of life and property. This pillar evaluates the degree to which communities are living safely with fire and are accepting of management and natural ecological dynamics. It also evaluates the capacity for communities to manage desired, beneficial fire and suppress unwanted fire.

The definition of WUI used here, from Carlson et al 2022, adopts the definitions of interface and intermix WUI developed for previous census-based WUI mapping efforts based on U.S. Federal Register definitions (Radeloff et al., 2005; USDA & USDI, 2001). According to the definitions used for the building-based maps and for the census-based maps, WUI is where building density exceeds 6.17 units/km2 and where land cover is either (1) at least 50% wildland vegetation (intermix) or (2) under 50% wildland vegetation but within 2.4 km (1.5 miles) of a patch of wildland vegetation at least 5 km2 in area that contains at least 75% vegetation (interface). The distance selected for the interface definition is based on research from the California Fire Alliance suggesting that this is the average distance firebrands can travel from an active wildfire front (Stewart et al., 2007).

DESIRED OUTCOME: Communities have adapted to live safely in forested landscapes and understand the significance of fire to maintaining healthy forests. They have sufficient capacity to manage desired fire and suppress unwanted fire.

HAZARD

The fire hazard element characterizes the fire risk in the wildland urban interface (WUI) defense and threat zones.

STRUCTURE EXPOSURE SCORE

Tier: 1

Data vintage: 08/2022. Includes disturbances through the end of 2021.

Metric Definition and Relevance: This metric combines two data layers; one is the Wildland Urban Interface (WUI) as defined by Carlson et al. 2022 (see WUI definition section for more information), and a second data layer, Structure Exposure Score (SES), developed by Pyrologix LLC. The WUI includes the intermix and interface zones which collectively identify areas where structures occur and/or where structures are within a 1.5 miles wildland vegetation (see definition above) . The distance selected for the interface definition is based on research from the California Fire Alliance suggesting that this is the average distance firebrands can travel from an active wildfire front.

Structure Exposure Score is an integrated rating of wildfire hazard that includes the likelihood of a wildfire reaching a given location along with the potential intensity and ember load when that occurs. SES varies considerably across the landscape.

Pyrologix uses a standard geometric-interval classification to define the ten classes of SES, where each class break is 1.5 times larger than the previous break. So, homes located within Class X are 1.5 times more exposed than those in Class IX, and so on. This metric represents SES for WUI areas only.

1. 1 (SES I): 0
2. 2 (SES II): 0.01 to 50

3. 3 (SES III): 50 to 75
4. 4 (SES IV): 75 to 113
5. 5 (SES V): 113 to 169
6. 6 (SES VI): 169 to 253
7. 7 (SES VII): 253 to 380
8. 8 (SES VIII): 380 to 570
9. 9 (SES IX): 570 to 854
10. 10 (SES X): 854+

Data Resolution: 30m Raster

Data Units: Relative index, 10 classes

Creation Method:

WUI:

The current delineation of the WUI (Carlson et al. 2022) uses a mapping algorithm with definitions of the WUI; two classes of WUI were identified:

- the intermix, where there is at least 50% vegetation cover surrounding buildings
- the interface, where buildings are within 2.4 km (1.5 miles) of a patch of vegetation at least 5 km^2 in size that contains at least 75% vegetation.

Both classes required a minimum building density of 6.17 buildings per km^2 (using a range of circular neighborhood sizes).

This is a proprietary index developed by Pyrologix, representing the level of wildfire exposure for a structure (e.g., a home) if one were to exist on a given pixel. It is an integrated measure that includes three components: the likelihood of a wildfire of any intensity occurring in a given year (annual burn probability), potential wildfire intensity for a given pixel, and ember load to that pixel from surrounding vegetation.

SES data was produced by Pyrologix LLC, a wildfire threat assessment research firm, as part of a spatial wildfire hazard assessment across all land ownerships for the state of California. The ongoing work generally follows the framework outlined in Scott and Thompson (2013), with custom methods and significant improvements developed by Pyrologix. The project generally consists of three components: fuelscape calibration and updates, wildfire hazard assessment, and risk assessment. It utilizes a combination of wildfire models and custom tools, including the FSim large wildfire simulator (Finney et al., 2011), and WildEST, a custom modeling tool developed by Pyrologix (Scott, 2020). To date, this work has resulted in a wide variety of spatial data layers related to wildfire hazard and risk, including Structure Exposure Score (SES), representing conditions prior to the 2020, 2021 and 2022 fire seasons. Work to date has been funded by the USDA Forest Service Region 5, the California Energy Commission, and the USDI Bureau of Land Management with data contributions from CAL FIRE.

For this project, the FSim large-fire simulator is used to quantify annual wildfire likelihood across the analysis area. FSim is a comprehensive fire occurrence, growth, behavior, and suppression simulation system that uses locally relevant fuel, weather, topography, and historical fire occurrence information to make a spatially resolved estimate of the contemporary likelihood and intensity of wildfire across the landscape.

WildEST (Wildfire Exposure Simulation Tool) is used to quantify wildfire intensity and ember loads across the analysis area. WildEST is a deterministic wildfire modeling tool developed by Pyrologix that integrates spatially continuous weather input variables, weighted based on how they will likely be realized on the landscape. This makes the deterministic intensity values developed with WildEST more robust for use in effects analysis than the stochastic intensity values developed with FSim. This is especially true in low wildfire occurrence areas where predicted intensity values from FSim are reliant on a very small sample size of potential weather variables. It also allows for more appropriate weighting of high-spread conditions into fire behavior calculations. WildEST also produces indices of conditional and expected ember production from vegetated areas (pixels) and load to other pixels in the analysis area. Please reference the Pyrologix 2021 project report (Volger et al., 2021) for more information on WildEST analysis.

FSim was run for the CAL 2022 fuelscape at 120m resolution. WildEST was run for the CAL 2022 fuelscape at 30-m resolution. Both models utilized gridded hourly historical California weather data provided by CALFIRE. Results for annual burn probability (FSim), fire intensity (WildEST) and ember load (WildEST) were used to create Structure Exposure Score.

Data Source:

Pyrologix, LLC

WUI, Carlson et al, 2022

File Name: StructureExposureScore_WUI_2022.tif

DAMAGE POTENTIAL

Tier: 1

Data Vintage: 08/2022. Includes disturbances through the end of 2021.

Metric Definition and Relevance: This metric combines two data layers; one is the Wildland Urban Interface (WUI) as defined by Carlson et al. 2022 (see WUI definition section for more information), and a second data layer, Damage Potential (DP), developed by Pyrologix LLC. The WUI includes the intermix and interface zones which collectively identify areas where structures occur. The distance selected for the interface definition is based on research from the California Fire Alliance suggesting that this is the average distance firebrands can travel from an active wildfire front.

The composite Damage Potential (DP) dataset represents a relative measure of wildfire's potential to damage a home or other structure if one were present at a given pixel, and if a wildfire were to occur (conditional exposure). It is a function of ember load to a given pixel, and fire intensity at that pixel, and considers the generalized consequences to a home from fires of a given intensity (flame length). This index does not incorporate a measure of annual wildfire likelihood.

Data Resolution: 30m Raster

Data Units: Relative index, low to high

Creation Method: This metric represents DP for WUI areas only. DP values were binned based on the following ranges into 6 classes and assigned class names.

- 0 (None): Values = 0
- 1 (Very Low): Values 0.01 to 20
- 2 (Low): Values 20 to 35
- 3 (Moderate): Values 35 to 50
- 4 (High): Values 50 to 80
- 5 (Very High): Values 80+

The current delineation of the WUI (Carlson et al. 2022) uses a mapping algorithm with definitions of the WUI; two classes of WUI were identified:

- the intermix, where there is at least 50% vegetation cover surrounding buildings
- the interface, where buildings are within 2.4 km (1.5 miles) of a patch of vegetation at least 5 km^2 in size that contains at least 75% vegetation.

Both classes required a minimum building density of 6.17 buildings per km^2 (using a range of circular neighborhood sizes).

Damage Potential (DP) data was produced by Pyrologix LLC, a wildfire threat assessment research firm, as part of a spatial wildfire hazard assessment across all land ownerships for the state of California. The ongoing work generally follows the framework outlined in Scott and Thompson (2013), with custom methods and significant improvements developed by Pyrologix. The project generally consists of three components: fuelscape calibration and updates, wildfire hazard assessment, and risk assessment. It utilizes a combination of wildfire models and custom tools, including WildEST (Wildfire Exposure Simulation Tool), a custom modeling tool developed by Pyrologix (Scott, 2020). To date, this work has resulted in a wide variety of spatial data layers related to wildfire hazard and risk, including Damage Potential (DP), representing conditions prior to the 2020, 2021 and 2022 fire seasons. Work to date has been funded by the USDA Forest Service Region 5, the California Energy Commission, and the USDI Bureau of Land Management with data contributions from CAL FIRE. Please reference the Pyrologix 2021 project report (Volger et al., 2021) for more information about the project or WildEST analysis.

Damage Potential (DP) is a proprietary index developed by Pyrologix LLC representing wildfire's potential to damage a home or other structure if a wildfire were to occur (conditional exposure). It is a function of ember load to a given pixel and fire intensity at that pixel, and it considers the generalized consequences to a home from fires of a given intensity (flame length). DP is calculated based on two other datasets developed by Pyrologix: conditional risk to potential structures (cRPS) and conditional ember load index (cELI).

cRPS represents the potential consequences of fire to a home at a given location if a fire occurs there and if a home were located there. It is a measure that integrates wildfire intensity with generalized consequences to a home on every pixel. Wildfire intensity (flame length) is calculated using Pyrologix' WildEST tool. WildEST is a scripted geospatial process used to perform multiple deterministic simulations under a range of weather types (wind speed, wind direction, fuel moisture content). Rather than weighting results solely according to the temporal relative frequencies of the weather scenarios, the WildEST process integrates results by weighting them according to their weather type probabilities (WTP), which appropriately weights high-spread conditions into the calculations. For fire-effects calculations, WildEST generates flame-length probability rasters that incorporate non-heading spread directions, for which fire intensity is considerably lower than at the head of the fire.

The response function characterizing potential consequences to an exposed structure is applied to fire effects flame lengths from WildEST for all burnable fuel types on the landscape regardless of whether an actual structure is present or not. The response function does not consider building materials of structures and is meant as a measure of the effect of fire intensity on structure exposure. The response function is provided below:

- Flame length probability of 0-2 ft: -25
- Flame length probability of 2-4 ft: -40
- Flame length probability of 4-6 ft: -55
- Flame length probability of 6-8 ft: -70
- Flame length probability of 8-12 ft: -85
- Flame length probability of >12 ft: -100

These results were calculated using 30m fire-effects flame-length probabilities from the WildEST wildfire behavior results and then further smoothed.

cELI is also calculated in WildEST, and represents the relative ember load per pixel, given that a fire occurs, based on surface and canopy fuel characteristics, climate, and topography within the pixel. Units are the relative number of embers. cELI is based on heading-only fire behavior.

Damage Potential is then calculated as the arithmetic mean of cELI and cRPS for each pixel across the landscape as follows:

$DP = cRPS + cELI/2$

Although flame length and its potential impact to structures is a function of the fire environment at the subject location only, ember load is a function of ember production and transport in the area surrounding the subject location. A location with light fuel (and therefore low flame length) could still have significant Damage Potential if surrounded by a fire environment that produces copious embers.

Data Source:

Pyrologix, LLC

WUI, Carlson et al, 2022

File Name: DamagePotential_WUI_2022.tif

EMBER LOAD INDEX

Tier: 1

Data Vintage: 08/2022. Includes disturbances through the end of 2021.

Metric Definition and Relevance: This ember load dataset represents the ember load index (ELI) per pixel, for a given pixel, based on surface and canopy fuel characteristics, climate, and topography within the pixel. The Ember Load Index (ELI) incorporates burn probability (BP). BP is incorporated into calculations of the ember production before the distribution of embers across the landscape to determine ember load. Given that ELI incorporates burn probability, this index can be used to identify where on the landscape hardening buildings may be needed to resist ignition and the priority for doing so according to the likelihood of the area being visited by fire.

Data Resolution: 30m Raster

Data Units: Relative number of embers.

Creation Method: ELI is not simply the multiplication of ember load (ELI) and burn probability (BP). Rather, BP is incorporated into calculations of the ember production prior to the distribution of embers across the landscape to determine ember load. ELI is based on heading-only fire behavior.

Data Source: Pyrologix, LLC

File Name: EmberLoadIndex_2022.tif

IGNITION CAUSE

Tier: 1

Data Vintage: 1992 - 2020

Metric Definition and Relevance: The original point layer (WildfireOccurrence_CA_1992_2020.shp) contains a spatial database of wildfires that occurred in the United States from 1992 to 2020. It is the fifth update of a publication originally generated to support the national Fire Program Analysis (FPA) system. The wildfire records were acquired from the reporting systems of federal, state, and local fire organizations. The following core data elements were required for records to be included in this data publication: discovery date, final fire size, and a point location at least as precise as a Public Land Survey System (PLSS) section (1-square mile grid). The data were transformed to conform, when possible, to the data standards of the National Wildfire Coordinating Group (NWCG), including an updated wildfire-cause standard (approved August 2020). Basic error-checking was performed and redundant records were identified and removed, to the degree possible. The resulting product, referred to as the Fire Program Analysis fire-occurrence database (FPA FOD), includes 2.3 million geo-referenced wildfire records, representing a total of 180 million acres burned during the 29-year period. Identifiers necessary to link the point-based, final-fire-reporting information to published large-fire-perimeter and operational-situation-reporting datasets are included. Short, Karen C. 2022. Spatial wildfire occurrence data for the United States, 1992-2020 [FPA_FOD_20221014]. 6th Edition. Fort Collins, CO: Forest Service Research Data Archive. https://doi.org/10.2737/RDS-2013-0009.6

Data Resolution: Vector(points) and 30m Raster

Data Units: Categorical

Creation Method: Rocky Mountain Research Station (U.S. Forest Service) scientist, Karen Short, is the principal creator of this data set. Points were converted to 30m raster cells using the "most frequent" function on the NWCG_CAUSE_CLASSIFICATION attribute (Broad classification of the reason the fire occurred) creating three rasters:

- Human caused ignition
- Lightning (natural) caused ignition
- All causes of ignition - Human or Natural and Missing data/not specified/undetermined

"MostFrqCau" indicates the most frequent cause of the fire in that location.. "FireCount" indicates the number of fires that occurred between 1992 and 2020, regardless of cause. It is noted that locations with hundreds of counts may be a result of the method of how ignitions are reported/recorded. Both the accuracy and precision of the location estimates are generally much lower than that implied by the stored coordinate information – which, for example, may have been calculated from a PLSS section centroid. Efforts were made to purge redundant records to the best of the authors' ability. Despite this, some locations may have multiple records that may reflect redundant records or multiple reports of fires due to the imprecision of the location record, the reporting process of an individual authority, or the possible reality of multiple initiations at a given location.

Data Source: Rocky Mountain Research Station, U.S. Forest Service

File Name: WldfireAllCausesCount_1992_2020.tif; WldFireOccCause_Human_1992_2020.tif; WldFireOccCause_Natural_1992_2020.tif; WildfireOccurrence_CA_1992_2020.shp

SOURCE OF EMBER LOAD TO BUILDINGS

Tier: 1

Data Vintage: 08/2022. Includes disturbances through the end of 2021.

Metric Definition and Relevance: The ember transport model used in WildEST tracks the travel of embers from each source pixel to downwind receiving pixels. The relative number of embers landing on a given receiving pixel is summed across all potential source pixels. If the receiving pixel has a nonzero WRC Building Cover value (meaning the pixel is within 75 m of a qualifying building), then we separately sum the relative number of embers from the source pixel. The final SELB raster represents the expected annual relative ember production that lands on building cover across all weather types.

Data Resolution: 30m Raster

Data Units: Relative index

Creation Method: The WildEST modeling contains a module for producing indices of conditional and expected ember production and load. The Conditional Ember Production Index (cEPI) is an index of the relative number of embers lofted at a given landscape pixel given the fire environment there, given that a fire occurs. Ember Production Index (EPI) is the expected value of cEPI; it is the expected annual relative number of embers lofted from a given landscape pixel.

The Conditional Ember Load Index (cELI) is a relative index of the relative number of embers that land at a given landscape location, including nonburnable pixels. Finally, Ember Load Index combines the conditional ELI and the likelihood of that ember load occurring. All ember characteristics are based on headfire behavior. These

The ember load indices represent relative ember load at a pixel. Similar to ember production, ember load is also based on surface and canopy fuel characteristics, climate, and topography at the pixel. Ember load incorporates downwind ember travel.

The Ember Load Index (ELI) incorporates burn probability; however, ELI is not simply the multiplication of condition ember load (cELI) and burn probability (BP). Rather, BP is incorporated into calculations of the ember production before the distribution of embers across the landscape to determine ember load. Given that ELI incorporates burn probability, this index can be used to identify where on the landscape hardening buildings may be needed to resist ignition and the priority for doing so according to the likelihood of the area being visited by fire.

Data Source: Pyrologix, LLC

File Name: SourceEmberLoadToBuildings_2022.tif

WILDFIRE HAZARD POTENTIAL

Tier: 1

Data Vintage: 08/2022. Includes disturbances through the end of 2021.

Metric Definition and Relevance: Wildfire Hazard Potential (WHP) is an index that quantifies the relative potential for wildfire that may be difficult to control. WHP can be used as a measure to help prioritize where fuel treatments may be needed.

Data Resolution: 30m Raster

Data Units: Relative index

Creation Method: Pyrologix calculated WHP following the methods established by Dillon et al. (2015) and Dillon (2018). The original methods utilize lower-resolution FSim inputs, while our approach uses higher-resolution inputs including 30-m CAL vegetation inputs (derived from LANDFIRE 2016), 30-m CAL fuel model outputs, 30-m CAL burn probability results, and 30-m CAL fire-effects flame-length probabilities from the WildEST wildfire behavior results.

Data Source: Pyrologix, LLC

File Name: WildfireHazardPotential_2022.tif

FIRE DYNAMICS

Fire dynamics reflect fire as an ecological process and the function that it performs. It can be broken into two key elements: functional fire and fire severity. Although fire dynamics pertain to the entire landscape, the ecological role of fire is most relevant to landscapes outside of the wildland urban interface (WUI). Within the WUI, protection of life and property takes priority over the role of fire as a process. As a result, this fire dynamics pillar pertains largely to areas outside of the WUI while the fire-adapted communities pillar pertains largely to areas inside the WUI.

DESIRED OUTCOME: Fire burns in an ecologically beneficial and socially acceptable way that perpetuates landscape heterogeneity and rarely threatens human safety or infrastructure.

FUNCTIONAL FIRE

Increasing the pace and scale of restoration on the landscape will require using a variety of tools to accomplish restoration targets. The use of prescribed fire and managed wildfires, where appropriate, can contribute to the restoration need. This is particularly true where fires burn at low and moderate severity, which we are referring to as “functional fire”. Functional fire is when fire burns in an ecologically beneficial and socially acceptable way, perpetuating landscape heterogeneity and rarely threatening human safety or infrastructure.

ANNUAL BURN PROBABILITY

Tier: 1

Data Vintage: 08/2022. Includes disturbances through the end of 2021.

Metric Definition and Relevance: Annual Burn Probability represents the likelihood of a wildfire of any intensity occurring at a given location (pixel) in a single fire season. In a complete assessment of wildfire hazard, wildfire occurrence and spread are simulated in order to characterize how temporal variability in weather and spatial variability in fuel, topography, and ignition density influence wildfire likelihood across a landscape. In such cases, the hazard assessment includes modeling of burn probability, which quantifies the likelihood that a wildfire will burn a given point (a single grid cell or pixel) during a specified period of time. Burn probability for fire management planning applications in this case is reported on an annual basis - the probability of burning during a single fire season.

Data Resolution: 30m Raster

Data Units: Probability, 0 to 1

Creation Method: Annual Burn Probability was produced by Pyrologix LLC, a wildfire threat assessment research firm, as part of a spatial wildfire hazard assessment across all land ownerships for the state of California. The ongoing work generally follows the framework outlined in Scott and Thompson (2013), with custom methods and significant improvements developed by Pyrologix. The project generally consists of three components: fuelscape calibration and updates, wildfire hazard assessment, and risk assessment. It utilizes a combination of wildfire models and custom tools, including the FSim large wildfire simulator (Finney et al., 2011). To date, this work has resulted in a wide variety of spatial data layers related to wildfire hazard and risk, including Annual Burn Probability, representing conditions prior to the 2020, 2021 and 2022 fire seasons. Work to date has been funded by the USDA Forest Service Region 5, the California Energy Commission, and the USDI Bureau of Land Management with data contributions from CAL FIRE.

For this project, the USFS modeling system called FSim is used to quantify annual wildfire likelihood across California. The model is parameterized using spatial datasets of historical weather, fire occurrence, fuels, weather, and topography in order to simulate thousands of fire-years on a landscape. Annual Burn Probability is calculated from these simulations using a Monte Carlo approach to make a spatially resolved estimate of the contemporary annual likelihood of wildfire across the landscape. For more information on FSim or the wildfire hazard modeling being performed by Pyrologix, please see Volger et al., 2021.

Data Source: Pyrologix, LLC

File Name: AnnualBurnProbability2022.tif

SEVERITY

Uncharacteristic proportions of high severity fire over the area burned, particularly in the last decade, has been a common theme in the megafires that have occurred throughout the Central Coast Region recently. The following metrics characterize, map, and quantify some of the factors that contribute.

PROBABILITY OF HIGH FIRE SEVERITY

Tier: 1

Data Vintage: 08/2022. Includes disturbances through the end of 2021.

Metric Definition and Relevance: These metrics depicts the probability of high severity fire as constructed by Pyrologix LLC. This operational-control probability raster indicates the probability that the headfire flame length in each pixel will exceed 8 foot flame lengths, the threshold that defines fires that would exceed manual control.

Data Resolution: 30m Raster

Data Units: Probability, 0 to 1

Creation Method: Probability of High Fire Severity (defined as >8 ft) was produced by Pyrologix LLC, a wildfire threat assessment research firm, as part of a spatial wildfire hazard assessment across all land ownerships for the state of California. The ongoing work generally follows the framework outlined in Scott and Thompson (2013), with custom methods and significant improvements developed by Pyrologix. The project generally consists of three components: fuelscape calibration and updates, wildfire hazard assessment, and risk assessment. To date, this work has resulted in a wide variety of spatial data layers related to wildfire hazard and risk, including operational control probabilities based on conditions prior to the 2020, 2021 and 2022 fire seasons. Work to date has been funded by the USDA Forest Service Region 5, the California Energy Commission, and the USDI Bureau of Land Management with data contributions from CAL FIRE. Please reference the Pyrologix 2021 project report (Volger et al., 2021) for more information.

Pyrologix uses the Wildfire Exposure Simulation Tool (WildEST) to develop this data layer, a deterministic wildfire modeling tool that integrates variable weather input variables and weights them based on how they will likely be realized on the landscape. WildEST is more robust than the stochastic intensity values developed with FSim. This is especially true in low wildfire occurrence areas where predicted intensity values from FSim are reliant on a very small sample size of potential weather variables.

Data Source: Pyrologix, LLC

File Name: ProbabilityHighFireSev_2022.tif

FOREST AND SHRUBLAND RESILIENCE

Forest and shrubland resilience is the ability of forest and shrubland vegetation and structure to remain a forest or shrubland in the face of disturbance (e.g., fire, forest management, climate change, etc.). The Forest and Shrubland Resilience Pillar evaluates forest and shrubland vegetation composition and structure to determine its alignment with desired disturbance dynamics and within tolerances of current and future biophysical conditions when considering changes due to climate change. The last 100 years of forest and shrubland management, combined with changing climates, have resulted in forest and shrubland structure and composition which are not resilient to contemporary disturbances. Forest or shrubland structure and composition are one of the few elements of a wildland that management can modify through treatments to improve conditions.

DESIRED OUTCOME: Vegetation composition and structure align with topography, desired disturbance dynamics, and landscape conditions, and are adapted to climate change.

STRUCTURE

Forest or shrubland structure is the spatial distribution of vegetation (live and dead) both vertically and horizontally on the landscape. Prior to European settlement, forests in the Central Coast Region were characterized by heterogeneous spatial patterns replete with individual large trees, gaps, and tree clumps of various sizes – patterns that were shaped by recurrent fire and other disturbances. After a century-plus of fire exclusion, timber harvesting, agricultural development, urbanization, and other land-use practices, the predominant trend across Californian landscapes is that they have become less resilient to natural and human-caused disturbances. In many cases some sort of restoration treatment may be necessary to reverse these trends.

CANOPY LAYER COUNT

Tier: 1

Data Vintage: 06/2020

Metric Definition and Relevance:

This layer represents the number of distinct vertical canopy layers of trees. Vertical layer count is a proxy for leaf area index, and maps canopy complexity. Since LANDFIRE doesn’t support a NoData value, all NoData pixels in canopy fuel metrics were set to 0 in the Landscape files. (e.g., canopy cover was set to 0 in all NoData locations). Topographic data and surface fuel model remain unaltered.

Data Resolution: 10m Raster

Data Units: Count

Creation Method: Each forest structure metric was derived directly from airborne lidar data, hosted by the USGS 3D Elevation Program. However, these data are only available for a small fraction of California’s 423,970 km² area.

To overcome this, we trained deep learning models—a form of pattern recognition—to identify these forest structure patterns in satellite imagery, then mapped each metric statewide.

These algorithms are of the U-net family of neural network architectures that perform pixel-wise regression and classification tasks. The satellite data includes imagery from Sentinel-1 C-band radar sensors and Sentinel-2 multispectral sensors at 10 m spatial resolution, collected in Fall 2019. Future versions will include imagery from PlanetScope multispectral sensors at 3 m resolution.

Downloaded from [California Forest Observatory - Organizations - WIFIRE Commons Data Catalog (sdsc.edu)](). For more information, go to https://forestobservatory.com/about.html#about

Data Source: California Forest Observatory (Salo Sciences), 2020

File Name: CFO_CanopyLayerCount2020Summer.tif

CANOPY VEG HEIGHT

Tier: 1

Data Vintage: 06/2020

Metric Definition and Relevance: This layer represents distance between the ground and the top of the canopy. Canopy height is a proxy for aboveground biomass and the amount of foliage that may be consumed in a canopy fire. Since LANDFIRE doesn't support a NoData value, all NoData pixels in canopy fuel metrics were set to 0 in the Landscape files. (e.g., canopy cover was set to 0 in all NoData locations). Topographic data and surface fuel model remain unaltered.

Data Resolution: 10m Raster

Data Units: meters, min 0 - max 80; each pixel value represents the average height above ground for vegetation within that pixel

Creation Method: Each forest structure metric was derived directly from airborne lidar data, hosted by the USGS 3D Elevation Program. However, these data are only available for a small fraction of California's 423,970 km² area. To overcome this, we trained deep learning models—a form of pattern recognition—to identify these forest structure patterns in satellite imagery, then mapped each metric statewide.

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Downloaded from [California Forest Observatory - Organizations - WIFIRE Commons Data Catalog (sdsc.edu)](). For more information, go to https://forestobservatory.com/about.html#about

Data Source: California Forest Observatory (Salo Sciences), 2020

File Name: CFO_CanopyHeight2020Summer.tif

CANOPY VEG COVER

Tier: 1

Data Vintage: 06/2020

Metric Definition and Relevance: This layer represents horizontal cover fraction occupied by tree canopies. Maps community type & fire regime, as well as available habitat for tree-dwelling species.

Data Resolution: 10m Raster

Data Units: Canopy cover is a 0-100% cover fraction and may be more precisely described as "canopy density." It calculates the proportion of all lidar returns >=5m divided by the total number of returns in that grid cell. This, therefore, does not include all vegetation, but instead describes the density of vegetation in the canopy vertical stratum (veg 5m and taller).

Creation Method: Each forest structure metric was derived directly from airborne lidar data, hosted by the USGS 3D Elevation Program. However, these data are only available for a small fraction of California's 423,970 km² area. To overcome this, we trained deep learning models—a form of pattern recognition—to identify these forest structure patterns in satellite imagery, then mapped each metric statewide.

These algorithms are of the U-net family of neural network architectures that perform pixel-wise regression and classification tasks. The satellite data includes imagery from Sentinel-1 C-band radar sensors and Sentinel-2 multispectral sensors at 10 m spatial resolution, collected in Fall 2019. Future versions will include imagery from PlanetScope multispectral sensors at 3 m resolution.

Downloaded from California Forest Observatory - Organizations - WIFIRE Commons Data Catalog (sdsc.edu). For more information, go to https://forestobservatory.com/about.html#about

Data Source: California Forest Observatory (Salo Sciences), 2020

File Name: CFO_CanopyCover2020Summer.tif

COMPOSITION

The composition of a forest is a reference to the biodiversity of the landscape; this includes a diversity of vegetation species, types (e.g., trees, shrubs, forbs, etc.), and distribution. Tree species composition affects many aspects of forest dynamics and function. A diversity of tree and shrub species can confer greater resilience to climate change and beetle outbreaks. The vegetation composition also affects fire dynamics, water reliability, carbon pools and sequestration, and economic diversity pillars. Since European settlement and the adoption of fire suppression and logging, forests of the Central Coast Region shifted to increased dominance of shade-tolerant and fire-intolerant species like white fir and red fir, incense cedar, Douglas fir, and tanoak. Other species like ponderosa pine, Jeffrey pine, sugar pine, and black oak, which are more shade-intolerant and fire-tolerant, declined in coverage. With increasingly larger and higher-severity fires occurring, forest-cover loss may be significant and shrub cover will increase.

TREE COVER

Tier: 1

Data Vintage: 12/2021

Metric Definition and Relevance: Total tree cover as measured by the fractional non-overlapping absolute tree cover, viewed vertically. Provides a first order measure of vegetation type when combined with parallel observations of shrub and herbaceous cover. Data from the National Land Cover Database (NLCD) are used for training, and NLCD definitions for cover (for example, the distinction between tree vs shrub) are expected to be similar in the CECS data sets.

Data Resolution: 30m Raster

Data Units: Fractional non-overlapping absolute cover; continuous variable from 0 to 1.

Creation Method: Machine learning (Random Forest) using the National Land Cover Database for training and Landsat observations as predictors. See https://doi.org/10.1029/2021AV000654 for further information.

Data Source: CECS; https://california-ecosystem-climate.solutions/

File Name: VegCover_Tree_2021.tif

SHRUB COVER

Tier: 1

Data Vintage: 12/2021

Metric Definition and Relevance: Total shrub cover as measured by the fractional non-overlapping absolute shrub cover, viewed vertically. Provides a first order measure of vegetation type when combined with parallel observations of tree and herbaceous cover. Data from the National Land Cover Database (NLCD) are used for training, and NLCD definitions for cover (for example, the distinction between tree vs shrub) are expected to be similar in the CECS data sets.

Data Resolution: 30m Raster

Data Units: Fractional non-overlapping absolute cover; continuous variable from 0 to 1.

Creation Method: Machine learning (Random Forest) using the National Land Cover Database for training and Landsat observations as predictors. See https://doi.org/10.1029/2021AV000654 for further information.

Data Source: CECS; https://california-ecosystem-climate.solutions/

File Name: VegCover_Shrub_2021.tif

HERBACEOUS COVER

Tier: 1

Data Vintage: 12/2021

Metric Definition and Relevance: Total herbaceous cover as measured by the fFractional non-overlapping absolute herbaceous cover, viewed vertically. Provides a first order measure of vegetation type when combined with parallel observations of tree and herbaceous cover. Data from the National Land Cover Database (NLCD) are used for training, and NLCD definitions for cover (for example, the distinction between tree vs shrub) are expected to be similar in the CECS data sets.

Data Resolution: 30m Raster

Data Units: Fractional non-overlapping absolute cover; continuous variable from 0 to 1.

Creation Method: Machine learning (Random Forest) using the National Land Cover Database for training and Landsat observations as predictors. See https://doi.org/10.1029/2021AV000654 for further information.

Data Source: CECS; https://california-ecosystem-climate.solutions/

File Name: VegCover_Herb_2021.tif

DISTURBANCE

California forests evolved with a suite of frequent disturbances: wildfires (both from lightning and burning by indigenous people), bark beetle-caused mortality, drought-caused mortality, avalanches, landslides, and windthrow, all of which created forest heterogeneity across the landscape. This heterogeneity included variations in surface and ladder fuels, which moderated fire behavior and spread. The variations in stand density and forest opening also served as critical habitats for wildlife. Forested areas are now more homogeneous due to lack of disturbance. The lack of disturbance is evident in the forest structure.

CUMULATIVE TREE COVER LOSS

Tier: 1

Data Vintage: 12/2021

Metric Definition and Relevance: The cumulative loss of tree cover over a 30-year period (1992-2021). Tree cover loss reflects fires, harvest/management and dieoff. Only disturbances that are sufficient to trigger the Continuous Change Detection and Classification algorithm are included; low-level, diffuse dieoff is likely missed.

Data Resolution: 30m Raster

Data Units: Cumulative fractional non-overlapping absolute tree cover loss, where tree cover is a continuous variable from 0 to 1. Cumulative loss can exceed 1 in cases with multiple disturbances.

Creation Method: Vegetation disturbances were identified over the Landsat TM/ETM+/OLI era using the Continuous Change Detection and Classification algorithm (CCDC). The corresponding annual change in tree cover was determined with machine learning (Random Forest) using the National Land Cover Database for training and Landsat/CCDC observations as predictors; this produced a ~35-year stack of rasters that identified the locations and severity of tree cover loss. This stack was then summed for 1992-2021 to calculate the cumulative tree cover loss over a 30-year period. See https://doi.org/10.1029/2021AV000654 for further information.

Data Source: CECS; https://california-ecosystem-climate.solutions/

File Name: DistHist_Severe_Tree_19922021.tif

CUMULATIVE SHRUB COVER LOST

Tier: 1

Data Vintage: 12/2021

Metric Definition and Relevance: The cumulative loss of shrub cover over a 30-year period (1992-2021). Shrub cover loss reflects fires, harvest/management and dieoff. Only disturbances that are sufficient to trigger the Continuous Change Detection and Classification algorithm are included; low-level, diffuse dieoff is likely missed.

Data Resolution: 30m Raster

Data Units: Cumulative fractional non-overlapping absolute shrub cover loss, where shrub cover is a continuous variable from 0 to 1. Cumulative loss can exceed 1 in cases with multiple disturbances.

Creation Method: Vegetation disturbances were identified over the Landsat TM/ETM+/OLI era using the Continuous Change Detection and Classification algorithm (CCDC). The corresponding annual change in shrub cover was determined with machine learning (Random Forest) using the National Land Cover Database for training and Landsat/CCDC observations as predictors; this produced a ~35-year stack of rasters that identified the locations and severity of shrub cover loss. This stack was then summed for 1992-2021 to calculate the cumulative tree cover loss over a 30-year period. See https://doi.org/10.1029/2021AV000654 for further information.

Data Source: CECS; https://california-ecosystem-climate.solutions/

File Name: DistHist_Severe_Shrub_19922021.tif

RISK OF TREE DIEOFF DURING DROUGHT

Tier: 1

Data Vintage: 12/2021

Metric Definition and Relevance: A quantitative continuous variable that reflects the risk of tree dieoff during a significant drought period (SPI48 drought = -2).

Data Resolution: 30m Raster

Data Units: This is a dimensionless index that ranges from 0 to ~20000. Low values indicate minimal or no risk of tree dieoff during drought, either or both because there are few trees in the pixel and/or there is ample local moisture even during periods of extreme precipitation shortfall. High values indicate significant risk of tree dieoff during drought, as a result of both a high density of trees at the site and likelihood of extreme local moisture shortfall.

Creation Method: Calculated by combining information on the local moisture balance and tree density. Local moisture balance was calculated as the ratio of Annual Evapotranspiration with the canopy observed in 2021 to Precipitation during a SPI 48 drought = -2 based on local P observations during 1991-2020. This ratio quantifies the local moisture deficit/surplus that would be expected during a 48-month period with precipitation that is 2 standard deviations below the local 30 year Normal. Tree cover was determined from Landsat. See https://doi.org/10.1038/s41561-019-0388-5 for further information.

Data Source: CECS; https://california-ecosystem-climate.solutions/

File Name: Vulner_TreeDieoff_SPI-2_2021.tif

POTENTIAL CLIMATE REFUGIA -BASELINE (HISTORICAL) CONDITIONS

Tier: 3

Data Vintage: 1981 - 2010

Metric Definition and Relevance: This raster dataset represents habitat types (natural vegetation communities) and their distribution across the array of climate conditions that each separate habitat type is found in under the baseline climate conditions. A 2015 map of the state's natural vegetation compiled from multiple sources was classified to the National Vegetation Classification Standard's mid-level classification, called "Macrogroup". Thirty one natural vegetation macrogroups are identified in the map, covering 99.87% of the state's natural terrestrial vegetation, and occupying 353,271 km2.

This serves as the foundation from which habitat types will be exposed to predicted changes in climate. Data are arrayed across 0 to 1 in terms of their exposure to current climate conditions. This data layer provides a baseline of vegetation adapted to "historic" conditions; i.e. climate conditions from the recent past; 1980-2010.

Data Resolution: 270m Raster

Data Units: 0- 1. Low values indicate higher resilience to threats. High values indicate significant exposure to climate change. -1 represents 'non analog' areas, i.e. locations that are outside the historic climate envelope of a given vegetation type.

Creation Method: The vegetation climate exposure analysis takes advantage of the 2015 vegetation map compiled for California by CALFIRE. Each Macrogroup (MG) was analyzed to determine which California habitats and associated dominant plant species make up its definition. California habitats are defined by the California Department of Fish and Wildlife (CDFW) through their California Wildlife Habitat Relationship (WHR) models9. WHR types are made up of plant species, such as the dominant trees, shrubs, and smaller plants. CDFW experts determined which WHR types correspond to each individual macrogroup; this cross-walk was used to develop a list of the dominant plant species that comprise each macrogroup.

The climate space occupied by each distinct vegetation macrogroup (largely equivalent to a CWHR habitat type) from the current time period was identified. This was done by using the points for each type and applying a kernel density estimator on a 2-d surface composed of the first two principal components of the climate conditions. The result is a smoothed continuous point density surface, showing the prevalence of each vegetation type across the range of sampled climatic conditions. This surface was partitioned by fitting contour lines so that they enclose a proportion of the original points from the current time period. Contours were calculated at 5% increments. For example the innermost 5% contour line encloses the 5% of pixels for the given vegetation type which are at the core of the climate space for that type, as determined by its density in the climate space. Cells further away from the dense central core, are considered to be more marginal in the vegetation type's distribution. The outer contours are fit to enclose the 95-99% of climatically marginal points, with the last 1% of cells (beyond the 99% contour) being the most marginal. In addition, if a cell lies outside the space defined by the 99% contour of any vegetation type, it is considered to be "non-analog," which means that it experiences climatic conditions outside of the conditions where we have a good sample in the initial time period. Excluded from this assessment are non-vegetated types such as snow, open water, and ice; and non-natural landcover types mapped as vineyards, tilled earth, orchards and Urban.

For more information on methods for the development of these climate refugia data see:

Thorne et al. 2015

Thorne et al. 2016

Thorne et al. 2017

Thorne et al. 2020

Data Source: Information Center for the Environment, UC Davis

File Name: hst8110.tif

POTENTIAL CLIMATE REFUGIA - UNDER MODELED CLIMATE CHANGE (MIROC MODEL - HOTTER AND DRIER)

Tier: 3

Data Vintage: 2016

Metric Definition and Relevance: This raster dataset represents habitat types (CWHR habitat classes) and their predicted exposure to climate stress across the array of predicted climate conditions (separate layers for early (2010 - 2039), mid (2040-2069), and late century (2070-2099)) for all habitat types in comparison to the baseline climate conditions. This serves as the foundation from which habitat types will be exposed to predicted changes in climate. Data are arrayed across 0 to 1 in terms of their exposure to current climate conditions. These three data layers can be used to help land managers allocate limited resources for climate-adaptive field work by providing a view of climate risk that varies across the lands they manage.

The Climate Change Model used in this analysis is the Miroc Earth System Model. This ESM, named "MIROC-ESM", is based on a global climate model MIROC (Model for Interdisciplinary Research on Climate) which has been cooperatively developed by researchers in Japan and others. This model suggests a hotter and drier future. The emission scenario used is the RCP 8.5, which represents a range of warming statewide from 1.99 to 4.56°C and between a 24.8% decrease in precipitation and a 22.9% increase, respectively.

Data Resolution: 270m Raster

Data Units: 0- 1. Low values indicate higher resilience to threats. High values indicate significant exposure to climate change. -1 represents 'non analog' areas, i.e. locations that are outside the historic climate envelope of a given vegetation type.

Creation Method: The vegetation climate exposure analysis takes advantage of the 2015 vegetation map compiled for California, which is described above. The vegetation climate exposure model is implemented in the R programming language, and takes the vegetation and climate raster files as the primary input data. The values of the climate raster files were randomly sampled at 100,000 points on the landscape, which were used to fit a statistical model characterizing the relationship between the variables both in the current time and for the modeled future data.

At each of these 100,000 points, 9 hydro-climatic variables were sampled to characterize the range and variation of conditions in the study region. These variables were: annual mean minimum temperature (Tmin), annual mean maximum temperature (Tmax), annual precipitation (PPT), actual evapotranspiration (AET), potential evapotranspiration (PET), climatic water deficit (CWD), snowpack depth on April 1st, runoff, and recharge. The variation between these variables was modeled using a principal component analysis21 (PCA) to identify the dominant components of variation. The top-two principal components axes, representing about 79% of the variability across the four climate projections, were extracted as a two-dimensional space, and are portrayed as the axes for the PCA plots shown in each macrogroup chapter below. This was done to simplify the representation of the climate space, while maintaining the most important information on the variables to be associated with the observed vegetation distributions.

The climate space occupied by each distinct macrogroup from the current time period was identified. This was done by using the points for each type and applying a kernel density estimator on a 2-d surface composed of the first two principal components of the climate conditions. The result is a smoothed continuous point density surface, showing the prevalence of each vegetation type across the range of sampled climatic conditions. This surface was partitioned by fitting contour lines so that they enclose a proportion of the original points from the current time period. Contours were calculated at 5% increments. For example the innermost 5% contour line encloses the 5% of pixels for the given vegetation type which are at the core of the climate space for that type, as determined by its density in the climate space. Cells further away from the dense central core, are considered to be more marginal in the vegetation type's distribution. The outer contours are fit to enclose the 95-99% of climatically marginal points, with the last 1% of cells (beyond the 99% contour) being the most marginal. In addition, if a cell lies outside the space defined by the 99% contour of any vegetation type, it is considered to be "non-analog," which means that it experiences climatic conditions outside of the conditions where we have a good sample in the initial time period. As a result, the status of that point is uncertain. There are occasionally a few extreme points which appear to be far outside the general distribution for the type. These may be due to misclassified vegetation types in the source data, microclimatic conditions not captured by the climate data, historic anomalies in long-lived species, etc.

Climate exposure is the level of climate change expected in the areas where each macrogroup is dominating. This report uses the term "vegetation climate exposure analysis" to describe the following analysis which was conducted on each macrogroup. The vegetation climate exposure analysis is calculated using the mapped extent of each macrogroup. Every grid cell of each macrogroup was ranked as to its level of exposure, relative to the entire area of that macrogroup. This was done for the current time, and used to define the common climate found for each macrogroup. Once each type's "climate envelope" was defined, we then assessed how much every grid cell changed under various future climate projections. This allowed a measure of the vegetation stress, or climate exposure. The area extent of each macrogroup that will be lost from the most commonly occurring climate conditions (≤80%) and the area that will fall into current marginal, or stressed, climate conditions (>95%) or outside the current climate conditions was calculated. This approach is particularly useful for resource managers, who often are constrained to work in specified areas, and need estimates of what areas within their jurisdiction are likely to be highly stressed, and what areas are likely to be less stressed, in effect climate refuge areas.

To consider how refugial conditions from a range of stressors can inform conservation planning and management, the authors integrated metrics of refugial capacity across different domains, which are defined as social, ecological, or physical drivers, processes, or cycles that influence landscape structure, function, or composition. To persist in the California landscape, species and ecosystems may need refugia from shifting climatic conditions, including extremely hot summers and prolonged droughts, but non-climate stressors can also affect conservation outcomes. In this landscape, changes in fire frequency can be a significant stressor affecting plant community structure and persistence. Anthropogenic features that modify hydrologic flows alter the ability of watersheds to sustain functional habitats. And finally, protected areas are often designed to mitigate the impacts of anthropogenic activities; however, recreational activities may alter the refugial capacity of the protected land, affecting the ability of the landscape to sustain species and their habitats. We combined these individual metrics to assess landscape level refugial capacity.

Sites with high refugial capacity (super-refugia sites) have, on average, 30% fewer extremely warm summers, 20% fewer fire events, 10% less exposure to altered river channels and riparian areas, and 50% fewer recreational trails than the surrounding landscape. Our results suggest that super-refugia sites (∼8,200 km2) for some natural communities are underrepresented in the existing protected area network, a finding that can inform efforts to expand protected areas.

For more information on methods for the development of these climate refugia data see:

Thorne et al. 2015

Thorne et al. 2016

Thorne et al. 2017

Thorne et al. 2020

Data Source: Information Center for the Environment, UC Davis

File Name: miroc_85_1039.tif; miroc_85_4069.tif; miroc_85_7099.tif

POTENTIAL CLIMATE REFUGIA - COMBINED MODELED CLIMATE CHANGE (MIROC MODEL - (HOTTER AND DRIER) AND CNRM-CM5 (WETTER AND WARMER)

Tier: 3

Data Vintage: 2016

Metric Definition and Relevance: This raster dataset represents habitat types (Macro Veg Type, largely equivalent to CWHR habitat classes) and their predicted exposure to climate stress across the array of predicted climate conditions (separate layers for early (2010 - 2039), mid (2040-2069), and late century (2070-2099)) for all habitat types in comparison to the baseline climate conditions. This serves as the foundation from which habitat types will be exposed to predicted changes in climate. Data are arrayed across 0 to 1 in terms of their exposure to current climate conditions. These three data layers can be used to help land managers allocate limited resources for climate-adaptive field work by providing a view of climate risk that varies across the lands they manage.

This analysis uses both the Miroc Earth System Model and the CNRM-CM5. CNRM-CM5 is an Earth system model designed to run climate simulations. It consists of several existing models designed independently and coupled through the OASIS software. Both were used under the RCP 8.5 emission scenario given that this is more likely under current emission levels.

This data layer is provided as a summary of likely exposure results. Exposure Scores:

· 1 = Refugia: CNRM-CM5 only (CNRM exposure values < 80%)
· 2 = Refugia: MIROC-ESM only (MIROC exposure values < 80%)
· 3 = Refugia Consensus (both models agree exposure values < 80%)
· **8 = High Exposure (both models agree exposure values >95%)**
· **9 = Very High Exposure (both models agree exposure values >99%)**

Data Resolution: 270m Raster

Data Units: 0, 1, 2, 3, 8, 9 Low values indicate higher resilience to threats. High values indicate significant exposure to climate change. -1 represents 'non analog' areas, i.e. locations that are outside the historic climate envelope of a given vegetation type.

Creation Method: Each dominant species is scored for its sensitivity to, and ability to adapt (adaptive capacity) to climate change. Sensitivity refers to the degree to which changes in climate are thought to directly impact different species. Adaptive capacity refers to estimates of the degree to which different species can use their life history characteristics to moderate impacts from changing climate. These two sets of scores represent the biological attributes of the dominant species in each macrogroup. We scored each of the dominant species comprising each macrogroup, according to life history characteristics defined in attribute tables of the California Manual of Vegetation, and supplemented by information found in the USDA plants database and the Jepson Interchange, a web portal for California plant taxonomy. The scores were combined to generate a single sensitivity and adaptive capacity (S&A) score.

Climate exposure is the level of climate change expected in the areas where each macrogroup is dominating. This report uses the term "vegetation climate exposure analysis" to describe the following analysis which was conducted on each macrogroup. The vegetation climate exposure analysis is calculated using the mapped extent of each macrogroup. Every grid cell of each macrogroup was ranked as to its level of exposure, relative to the entire area of that macrogroup. This was done for the current time, and used to define the common climate found for each macrogroup. Once each type's "climate envelope" was defined, we then assessed how much every grid cell changed under various future climate projections. This allowed a measure of the vegetation stress, or climate exposure. The area extent of each macrogroup that will be lost from the most commonly occurring climate conditions (≤80%) and the area that will fall into current marginal, or stressed, climate conditions (>95%) or outside the current climate conditions was calculated. This approach is particularly useful for resource managers, who often are constrained to work in specified areas, and need estimates of what areas within their jurisdiction are likely to be highly stressed, and what areas are likely to be less stressed, in effect climate refuge areas.

To consider how refugial conditions from a range of stressors can inform conservation planning and management, the authors integrated metrics of refugial capacity across different domains, which are defined as social, ecological, or physical drivers, processes, or cycles that influence landscape structure, function, or composition. To persist in the California landscape, species and ecosystems may need refugia from shifting climatic conditions, including extremely hot summers and prolonged droughts, but non-climate stressors can also affect conservation outcomes. In this landscape, changes in fire frequency can be a significant stressor affecting plant community structure and persistence. Anthropogenic features that modify hydrologic flows alter the ability of watersheds to sustain functional habitats. And finally, protected areas are often designed to mitigate the impacts of anthropogenic activities; however, recreational activities may alter the refugial capacity of the protected land, affecting the ability of the landscape to sustain species and their habitats. We combined these individual metrics to assess landscape level refugial capacity.

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For more information on methods for the development of these climate refugia data see:

Thorne et al. 2015

Thorne et al. 2016

Thorne et al. 2017

Thorne et al. 2020

Data Source: Information Center for the Environment, UC Davis

File Name: combine85_all7.tif

BIODIVERSITY CONSERVATION

The California landscape provides habitat for over 300 species of native vertebrates and thousands of invertebrate species and plants. Management activities over the last century have impacted most species to varying degrees and some have declined significantly in recent decades. Protecting and enhancing native biodiversity has become a management imperative under both federal and state laws and policy. Native plants and animals provide a wide array of benefits to forests and other habitats in California; they help forests recover after a fire, control flooding and soil erosion, cycle nutrients, and are valued by people recreating in forests. Greater species diversity promotes adaptability and helps ecosystems withstand and recover from disturbance, including those caused by climate change. The Biodiversity Conservation pillar focuses on species diversity, critical habitat for focal species and non-native species distribution.

Habitat data to model the likelihood of species presence or absence was derived from the FVEG WHR data layer.

DESIRED OUTCOME: The network of native species and ecological communities is sufficiently abundant and distributed across the landscape to support and sustain their full suite of ecological and cultural roles.

SPECIES DIVERSITY

Species diversity is a function of both the number of different species in the community and their relative abundances. Larger numbers of species and more even abundances of species lead to higher species diversity. Species diversity can be calculated in a variety of ways to represent the type and magnitude of differences among species, their number, and their abundance.

CALIFORNIA RED-LEGGED FROG

Tier: 1

Data Vintage: 06/2001

Metric Definition and Relevance: This dataset represents a species habitat distribution map for California Red-legged Frog (*Rana draytonii)* within the conterminous United States (CONUS) based on 2001 ground conditions.

Data Resolution: 30m Raster

Data Units: Binary layer, 1 represents current habitat

Creation Method: This Gap Analysis Project (GAP) habitat map is a prediction of the spatial distribution of suitable environmental and land cover conditions within the United States for the species. Mapped areas represent places where the environment is suitable for the species to occur (i.e. suitable to support one or more life history requirements for breeding, resting, or foraging), while areas not included in the map are those predicted to be unsuitable for the species. While the actual distributions of many species are likely to be habitat limited, suitable habitat will not always be occupied because of population dynamics and species interactions. Furthermore, these maps correspond to midscale characterizations of landscapes, but individual animals may deem areas to be unsuitable because of presence or absence of fine-scale features and characteristics that are not represented in our models (e.g. snags, vernal pools, shrubby undergrowth). These maps are intended to be used at a 1:100,000 or smaller map scale.

This habitat map is created using a deductive model to predict areas suitable for occupation within a species range. The deductive habitat models are built by compiling information on the species' habitat associations and entering it into a relational database. Information is compiled from the best available characterizations of the species' habitat, which included species accounts in books and databases, primary peer-reviewed literature. The literature references for each species are included in the "Species Habitat Model Report" and "Machine Readable Habitat Database Parameters" files attached to each habitat map item in the ScienceBase repository. The compiled habitat information is used by a biologist to determine which of the ecological systems and land use classes represented in the National Gap Analysis Project's (GAP) Land Cover Map Ver. 1.0 the species is associated with.

The maps are generated using a python script that queries the model parameters in the database; reclassifies the GAP Land Cover Ver 1.0 and ancillary data layers within the species' range; and combines the reclassified layers to produce the final 30m resolution habitat map. Map output is, therefore, not only a reflection of the ecological systems that are selected in the habitat model, but also any other constraints in the model that are represented by the ancillary data layers.

Credits: U.S. Geological Survey (USGS) - Gap Analysis Project (GAP), 2018, California Red-legged Frog (Rana draytonii) aCRLFx_CONUS_2001v1 Habitat Map: U.S. Geological Survey data release, https://doi.org/10.5066/F7T43RCM.

Data Source: USGS

File Name: california_red_legged_frog_habitat.tif

COMMUNITY INTEGRITY

The ability of communities to adapt to changing ecological, social, and economic conditions. This entails the capability of an ecological system to sustain a community of organisms that retains the pre-settlement species composition, diversity, and functional organization of natural habitats within a region.

HABITAT CONNECTIVITY

Tier: 1

Data Vintage: last updated 082019

Metric Definition and Relevance: The Terrestrial Connectivity dataset is one of the four key components of the California Department of Fish and Wildlife's (CDFW) Areas of Conservation Emphasis (ACE) suite of terrestrial conservation information. The dataset summarizes the relative ability of a species to move across the landscape between patches of suitable habitat. It shows a compilation of linkages, corridors, and natural landscape blocks identified in statewide and regional connectivity studies. Each hexagon (2.5 mi^2) is ranked into one of the following categories based on the identification of corridors and linkages in statewide, regional, and species-movement studies:

- 5: *Irreplicable and Essential Corridors* – The Nature Conservancy's (TNC) Omniscape model identifies channelized areas and priority species movement corridors. The mapped channelized areas are those areas where surrounding land use and barriers are expected to funnel, or concentrate, animal movement. These areas may represent the last available connection(s) between two areas, making them high priority for conservation.
- 4: *Conservation Planning Linkages* – Habitat connectivity linkages are often based on species-specific models and represent the best connections between core natural areas to maintain habitat connectivity. Linkages have more implementation flexibility than irreplaceable and essential corridors; any linkage areas not included in rank 5 are included here.
- 3: *Connections with Implementation Flexibility* – Areas identified as having connectivity importance but not identified as channelized areas, species corridors or habitat linkage at this time. Future changes in surrounding land use or regional specific information may alter the connectivity rank. Included in this category are areas mapped in the TNC Omniscape study as 'intensified', core habitat areas, and areas on the periphery of mapped habitat linkages.
- 2: *Large Natural Habitat Areas* – Large blocks of natural habitat (> 2000 acres) where connectivity is generally intact. This includes natural landscape blocks from the 2010 CEHC and updated with the 2016 Statewide Intactness dataset. Areas mapped as CEHC NLB and not include in the previous ranks, are included here.
- 1: *Limited Connectivity Opportunity* – Areas where land use may limit options for providing connectivity (e.g., agriculture, urban) or no connectivity importance has been identified in models. Includes lakes. Some DOD lands are also in this category because they have been excluded from models due to lack of conservation opportunity, although they may provide important connectivity habitat.

Data Resolution: 30m Raster

Data Units: Categorical; 5 (listed above)

Creation Method: Developed by CDFW, the Terrestrial Connectivity dataset summarizes information on terrestrial connectivity by ACE hexagon (2.5 mi^2) including the presence of mapped corridors or linkages and the juxtaposition to large, contiguous, natural areas. This dataset was developed to support conservation planning efforts by allowing the user to spatially evaluate the relative contribution of an area to terrestrial connectivity based on the results of statewide, regional, and other connectivity analyses. This map builds on the 2010 California Essential Habitat Connectivity (CEHC) map, based on guidance given in the 2010 CEHC report. The data are summarized by ACE hexagon.

The ACE Terrestrial Connectivity polygon has been converted to 30m Raster and the connectivity description attribute (HabDesc) is classified into the five connectivity ranks (detailed above).

Data Source: California Department of Fish and Wildlife; Terrestrial Connectivity, Areas of Conservation Emphasis (ACE), version 3.1

File Name: HabitatConnectivity_2019.tif

ECONOMIC DIVERSITY

Economic Diversity increases business opportunities that provide regional economic vitality and additional benefits to rural and vulnerable populations. Ecosystem services and forest products provide a foundation for many local and regional economic activities and employment opportunities. Forest management should support a sustainable natural resource-based economy.

DESIRED OUTCOME: Forest management and outdoor activities support a sustainable, natural-resource-based economy, particularly in rural communities.

WOOD PRODUCT INDUSTRY

The wood product industry, with some exceptions, is largely limited to the North Coast and Sierra Nevada Regions. However, restoration activities, including vegetation management, are necessary and require financial investments to make progress. This work brings jobs and income to local communities.

COST OF POTENTIAL TREATMENTS

Under development

CARBON SEQUESTRATION

Forests play an important role in mitigating climate by sequestering and storing large amounts of carbon. However, forests are at risk of losing carbon because of rates of decay and disturbance, especially with high severity wildfires. Knowing where carbon exists provides a context for where changes in forest conditions will have the greatest impact on carbon storage and sequestration objectives.

DESIRED OUTCOME: Carbon sequestration is enhanced in a stable and sustainable manner that yields multiple ecological and social benefits.

Note that all values for carbon have been expressed in Mg C/ha, the international standard for how carbon is measured. If needed, to convert back to the native short tons per acre, divide the Mg/ha by 2.2417023114334.

CARBON STORAGE

Carbon storage in forest biomass is an essential attribute of stable forest ecosystems and a key link in the global carbon cycle. After carbon dioxide is converted into organic matter by photosynthesis, carbon is stored in forests for a period of time before it is ultimately returned to the atmosphere through respiration and decomposition or disturbance (e.g., fire). A substantial pool of carbon is stored in woody biomass (roots, trunks, branches). Another portion eventually ends up as organic matter in forest floor litter and in soils. Soil carbon does not change very quickly and is difficult to measure directly.

TOTAL ABOVEGROUND CARBON

Tier: 1

Data Vintage: 09/2021

Metric Definition and Relevance: Identifying ecosystem carbon is essential to land managers and the Total Aboveground Carbon metric provides an estimate of the amount of existing carbon and its location on California's landscape. The metric also serves to provide context for the other metrics used to quantify carbon sequestration. For example, instability or lack of resilience in forests with low total aboveground carbon would be of less concern than the same degree of instability in a forest that has large total aboveground carbon.

Data Resolution: 30m Raster

Data Units: Grams dry matter/m2

Creation Method: The Center for Ecosystem Climate Solutions (CECS) DataEngine model tracks monthly carbon in multiple pools from 1986 to 2021. The carbon components are initialized with eMapR (see Additional Resources) observations for the early Landsat era; the model then runs freely based on Landsat and other observations. Disturbances and disturbance intensity are tracked annually by Landsat (see other metrics developed by CECS) and used to quantitatively transfer or combust pools. The model allocates and turns over material based on allometry scaling theory, as adjusted by observational data sets. Aboveground pools (live tree, live shrubs and dead material) are summed for September of 2021.

Data Source: CECS; https://california-ecosystem-climate.solutions/

File Name: CStocks_Total_Above_2021.tif

CARBON STABILITY

Carbon stability is an important feature in carbon sequestration calculations because carbon turnover – high levels of loss, even if followed by high rates of sequestration – are not as ecologically beneficial as high residency rates for carbon and larger pool values, particularly when stored in large live trees which have many other ecological benefits. The carbon in dead biomass is considered a more unstable component of the carbon pool itself, and a potential destabilizing factor for the live carbon pool in fire-adapted forest ecosystems, especially where it exceeds certain thresholds (e.g., over 46 Mg (total biomass)/ha, Stephens et al., 2022).

ABOVEGROUND CARBON TURNOVER TIME

Tier: 1

Data Vintage: 09/2021

Metric Definition and Relevance: The average lifetime of aboveground live and dead carbon in years. Locations where the lifetime or turnover time is longer have more carbon in more stable pools, such as large trees or large coarse woody debris. Locations where the lifetime or turnover time is shorter have more carbon in labile pools, such as live or dead leaves.

Data Resolution: 30m Raster

Data Units: Years

Creation Method: Calculated from the ratio of total aboveground carbon and annual decomposition. Aboveground carbon and annual decomposition are both calculated for 2021 from a Landsat-driven pools and fluxes model, as described for the total aboveground carbon product. Aboveground turnover time does not currently account for carbon losses and removals with combustion or harvest.

Data Source: CECS; https://california-ecosystem-climate.solutions/

File Name: CStocks_Turnovertime_2021.tif

WATER SECURITY

Forests serve as natural water collection, storage, filtration, and delivery systems as water flows from forests into rivers providing critical aquatic and wetland habitat, while also supplying water for drinking and agriculture. From a more mechanistic perspective, the energy and water balance of forest ecosystems are fundamentally linked. Water is essential to photosynthesis and the latent energy exchange of transpiration is a major driver of water loss. In short, the fate of forests directly influences the quantity and quality of California's freshwater supply.

DESIRED OUTCOME: Watersheds provide a reliable supply of clean water despite wide swings in annual precipitation, droughts, flooding, and wildfire.

QUANTITY

Understanding the interaction between water supply and ecosystem demand informs both the extent of moisture stress and the amount of water available for storage.

ACTUAL EVAPOTRANSPIRATION TO PRECIPITATION FRACTION DURING DROUGHT

Tier: 1

Data Vintage: 09/2021

Metric Definition and Relevance: Plants respond to conditions in their immediate vicinity. Thus, to understand the vegetative moisture stress during drought, it is important to measure the local moisture balance. The actual evapotranspiration fraction (AETF) provides such a measure. Specifically, it indicates whether a location is expected to experience local drying during a drought, or whether the location receives sufficient precipitation that it will remain moist even during an extended drought. An extended drought is defined by a 48-month period where the Standardized Precipitation Index (SPI, NCAR 2022) is two standard deviations below the long-term mean (SPI-48 = negative 2). Such a drought is expected approximately once every 50 years in the Central Coast Region.The AETF ranges from 0 to > 1; a low value indicates a wetter location during drought and a high value indicates a drier location. Locations <1 would be expected to generate runoff, even during a significant drought (SPI-48 drought = negative 2.0), and would be expected to continue generating runoff. Locations > 1 would be expected to desiccate the soil during drought, with negligible runoff, and increasing vegetation drought stress. AET/P does not account for lateral water inflow, either as runoff or irrigation.

Data Resolution: 30m Raster

Data Units: Dimensionless fraction (AET in mm/P in mm).

Creation Method: Calculated as the ratio of actual evapotranspiration (AET) during 2021 Water Year (WY) and precipitation that would be expected for each pixel under a significant drought (SPI-48 drought = negative 2.0). AET is calculated based on Landsat observations and eddy covariance, along with information on local monthly irradiance that accounts for Top of Atmosphere and topographic effects. The AET calculated for 2021 is then divided by the precipitation that would be expected for each pixel under a significant drought (SPI-48 drought = negative 2.0). This quantity of precipitation is calculated for each pixel based on local, down-scaled PRISM data for 1991-2020. This fraction provides a measure of the local water balance during drought, with the higher values indicating a drier location. See https://doi.org/10.1029/2012JG002027 and https://doi.org/10.1073/pnas.1319316111 for further information.

Data Source: CECS; https://california-ecosystem-climate.solutions/

File Name: WaterFlux_AETFrac_SPI-2_2021.tif

PRECIPITATION MINUS ACTUAL EVAPOTRANSPIRATION DURING AVERAGE CONDITIONS

Tier: 1

Data Vintage: 09/2021

Metric Definition and Relevance: Runoff is a measure of the water available for storage. It is determined by both the water supply and the demand of the existing vegetation. Annual mean runoff measures the "average" vegetative demand and thus provides a comparative index on the potential available runoff. Specifically, Annual Mean Runoff is the expected surplus water that would discharge to surface or groundwater flows during a series of years with average precipitation. Larger values indicate more runoff under mean conditions.

Data Resolution: 30m Raster

Data Units: mm/y

Creation Method: The Center for Ecosystem Climate Solutions at UC Irvine (CECS) is working with the State and Federal governments in developing scientifically rigorous, stakeholder-informed methods that have produced tailored, integrated data for land management decision makers. The CECS DataEngine model tracks monthly water balance from 1986 to 2021. The Annual Mean Runoff layer is calculated using this CECS DataEngine model logic forced with a series of 4 years that each received precipitation according to the timing and magnitude of the 30-year climate Normal Precipitation (SPI = 0 by definition).

The model water inputs are determined from downscaled PRISM gridded datasets (https://prism.oregonstate.edu/). In the case of the Annual Mean Runoff, this reflects the monthly 30 year Normal for each pixel calculated for 1991-2020. Actual evapotranspiration (AET) is calculated from Landsat observations and eddy covariance during 2021, along with information on local monthly irradiance that accounts for Top of Atmosphere (TOA) and topographic effects, as well as monthly temperature and drought stress. Precipitation Minus Actual Evapotranspiration is calculated as the difference; it provides an excellent measure of the long-term runoff from upland pixels. Areas with a higher P-ET produce greater runoff, and areas with a low P-ET tend to produce little or no runoff during average or dry years. See https://doi.org/10.1029/2012JG002027 and https://doi.org/10.1073/pnas.1319316111 for further information.

Data Source: CECS; https://california-ecosystem-climate.solutions/

File Name: WaterFlux_Runoff_SPI0_2021.tif

QUALITY

Understanding the interaction between water supply and ecosystem demand informs both the extent of moisture stress and the amount of water available for storage.

PERCENT IMPERVIOUS SURFACE

Tier: 1

Data Vintage: 06/2019

Metric Definition and Relevance: This National Land Cover Database (NLCD) product represents urban impervious surfaces as a percentage of developed surface over every 30-meter pixel of California, extracted from a nationwide layer. The definition of impervious means water does not seep into the ground, it runs off into storm sewers and then into local creeks. Examples of impervious surfaces include highways, streets and pavement, driveways, and house roofs. The relevance of impervious surfaces is the higher the proportion of impervious surfaces the more likely flooding can occur.

Data Resolution: 30m Raster

Data Units: Percent Imperviousness

Creation Method: The NLCD 2019 design aims to provide consistent and robust methodologies for production of a multi-temporal land cover and land cover change database from 2001 to 2019 at 2–3-year intervals. Comprehensive research was conducted and resulted in developed strategies for NLCD 2019: continued integration between impervious surface and all landcover products with impervious surface being directly mapped as developed classes in the landcover, a streamlined compositing process for assembling and preprocessing based on Landsat imagery and geospatial ancillary datasets; a multi-source integrated training data development and decision-tree based land cover classifications; a temporally, spectrally, and spatially integrated land cover change analysis strategy; a hierarchical theme-based post-classification and integration protocol for generating land cover and change products; a continuous fields biophysical parameters modeling method; and an automated scripted operational system for the NLCD 2019 production. For information see Data | Multi-Resolution Land Characteristics (MRLC) Consortium

Data Source: National Land Cover Database (NLCD)

File Name: nlcd_2019_imperviousPercent_CA.tif

AIR QUALITY

The goal of healthier forests is aligned with the goal of having healthier air (Cisneros et al., 2014, Long et al., 2018). Forests with sustainable fuel loads create less emissions overall, and support less rapid fire growth, which reduces emissions per day and decreases the chances that smoke from a wildland fire event will create long duration, intense smoke episodes like those we've seen at regional scales during the past decade. Key to supporting the proactive management of smoke and minimization of impacts is a granular understanding at the project scale of where the fuels are, and what potential emissions might occur under wildfire and/or Rx fire scenarios. Those emissions (e.g., from maps like those produced by F3 below) combined with estimates of daily spread can be used to inform operational or scenario-based dispersion modeling (and would be compatible with California's PFIRS smoke management system), which in turn would help fire and air managers better understand where smoke is likely to go, and help inform the public where and when it's likely to occur at potentially unhealthy concentrations.

Tradeoffs between wildfire and Rx fire smoke production (daily, or in total) could be quantified on a first order basis by summing daily or total emissions from high severity vs moderate severity over the area of the respective fire spread polygons. Note that Rx fire smoke impacts are not only different due to per acre differences in emissions, but because the per day emissions can also differ quite substantially. Those emissions numbers could also inform dispersion modeling scenarios showing the relative differences in smoke impacts between wildfire and prescribed scenarios, or even between different wildfire management scenarios.

DESIRED OUTCOME: Emissions from fires are limited to primarily low- and moderate-severity fires in wildland ecosystems. Forests improve air quality by capturing pollutants.

PARTICULATE MATTER

Particle pollution represents a main component of wildfire smoke and the principal public health threat. Fine particles (also known as PM2.5)are particles generally 2.5 µm in diameter or smaller and represent a main pollutant emitted from wildfire smoke. Fine particles from wildfire smoke are of greatest health concern.

TOTAL POTENTIAL SMOKE EMISSION - HIGH SEVERITY

Under development

WETLAND INTEGRITY

Wetlands provide critical habitat, store carbon, enhance water quality, control erosion, filter and retain nutrient pollution, and provide spaces for recreation. They are local and regional centers of biodiversity, and support species found nowhere else across western landscapes. Functional wetland ecosystems will serve increasingly important roles in buffering impacts from extreme climate events, and upland disturbances such as flooding and erosion. Meadow and riparian ecosystems provide ecosystem services and are key linkages between upland and aquatic systems in forested landscapes.

DESIRED OUTCOME: Wetland ecosystems are biologically intact, provide multiple ecosystem services, and meadow and riparian ecosystems provide key linkages between upland and aquatic systems in forested landscapes.

COMPOSITION

Wetland composition pertains to the array of different wetland types, their relative abundance, the uniqueness of their co-occurrence and composition, and their integrity in a given location and area within and across landscapes. Wetland ecosystems include all lentic (e.g. lakes, ponds, bogs, fens) and lotic (e.g., rivers, streams, springs, seeps) aquatic ecosystems, as well as associated vegetated wetlands such as wet meadows and riparian vegetation.

AQUATIC SPECIES RICHNESS

Tier: 1

Data Vintage: 02/2018

Metric Definition and Relevance: Aquatic native species richness is a measure of species biodiversity, and is one measurement used to describe the distribution of overall species biodiversity in California for the California Department of Fish and Wildlife (CDFW) Areas of Conservation Emphasis Project (ACE). Native species richness represents a count of the total number of native aquatic species potentially present in each watershed based on species range and distribution information. The data can be used to view patterns of species diversity, and to identify areas of highest native richness across the state. The species count consists of four taxonomic groups – fish, aquatic invertebrates, aquatic amphibians, and aquatic reptiles.

Data Resolution: 30m Raster

Data Units: Count

Creation Method: For more information, see the Aquatic Native Species Richness Factsheet (2018) at https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=150852

The California Department of Fish and Wildlife (CDFW) Areas of Conservation Emphasis (ACE) is a compilation and analysis of the best-available statewide spatial information in California on biodiversity, rarity and endemism, harvested species, significant habitats, connectivity and wildlife movement, climate vulnerability, climate refugia, and other relevant data (e.g., other conservation priorities such as those identified in the State Wildlife Action Plan (SWAP), stressors, land ownership). ACE addresses both terrestrial and aquatic data.

Data Source:

Aquatic Native Species Richness Summary, Areas of Conservation Emphasis (ACE), version 3.0, California Department of Fish and Wildlife (CDFW)
ACE database

File Name: aquatic_species_richness_CA_2018.tif

WETLAND DIVERSITY

Tier: 1

Data Vintage: 06/2018

Metric Definition and Relevance: This data set represents the extent, approximate location, and type of wetlands and deepwater habitats in California. These data delineate the areal extent of wetlands and surface waters as defined by Cowardin et al. (1979).

Data Resolution: 30m raster

Data Units: Thematic

Creation Method: Downloaded from the National Wetlands Inventory (NWI), polygon converted to 30 meter raster. For more information see [https://www.fws.gov/program/national-wetlands-inventory.](https://www.fws.gov/program/national-wetlands-inventory)

Definition of values:

- Lake = Lake or reservoir basin. Lacustrine wetland and deepwater (L).
- Freshwater Emergent Wetland = Herbaceous marsh, fen, swale and wet meadow. Palustrine emergent (PEM).
- Estuarine and Marine Wetland = Vegetated and non-vegetated brackish and saltwater marsh, shrubs, beach, bar, shoal or flat. Estuarine intertidal and Marine intertidal wetland (E2, M2).
- Other = Farmed wetland, saline seep and other miscellaneous wetland. Palustrine wetland (Misc. types, PUS, Pf..)
- Freshwater Pond = Pond. Palustrine unconsolidated bottom, Palustrine aquatic bed (PUB, PAB).
- Estuarine and Marine Deepwater = Open water estuary, bay, sound, open ocean. Estuarine and Marine subtidal water (E1, M1).
- Riverine = River or stream channel. Riverine wetland and deepwater (R).
- Freshwater Forested/Shrub Wetland = Forested swamp or wetland shrub bog or wetland. Palustrine forested and/or Palustrine shrub (PFO, PSS).

Data Source: The National Wetlands Inventory, US Fish & Wildlife Service (USFWS)

File Name: NWI_WetlandsType_2018_30m.tif

RIPARIAN HABITAT

Tier: 1

Data vintage: 04/2019

Metric Definition and Relevance: These data depict 10-meter raster riparian areas for 50-year flood heights for California in 2019.

Data Resolution: 10m Raster

Data Units: binary

Creation Method: Fifty-year flood heights were estimated using U.S. Geological Survey (USGS) stream gage information. NHDPlus version 2.1 was used as the hydrologic framework to delineate riparian areas. The U.S. Fish and Wildlife Service's National Wetland Inventory and USGS 10-meter digital elevation models were also used in processing these data. See https://doi.org/10.2737/RDS-2019-0030

Credits: Sinan Abood, Ph.D. GISP; Research Scientist, Forest Service Washington Office (WO) – Biological & Physical Resources (BPR)

Data Source: USDA Forest Service

File Name: RiparianAreas10m_2019.tif

SOCIAL AND CULTURAL WELL-BEING

The landscape provides a place for people to connect with nature, recreate, to maintain and improve their overall health, and an opportunity to contribute to environmental stewardship. While the elements of this pillar include public health and engagement, recreation quality, and equitable opportunities producing quantifiable, measurable and actionable metrics remains challenging. These metrics are still under development and insights into these potential metrics are appreciated.

DESIRED OUTCOME: The landscape provides a place for people to connect with nature, to recreate, to maintain and improve their overall health, and to contribute to environmental stewardship, and is a critical component of their identity.

EQUATIBLE OPPORTUNITY

Environmental Justice is the fair treatment and meaningful involvement of all people regardless of race, color, national origin or income regarding the development, implementation and enforcement of environmental laws, regulations, policies and land management.

POVERTY PERCENTILE

Tier: 1

Data Vintage: 10/2021

Metric Definition and Relevance: Percent of population living below two times the federal poverty level. The U.S. Census Bureau determines the federal poverty level each year. The poverty level is based on the size of the household and the age of family members. If a person or family's total income before taxes is less than the poverty level, the person or family are considered in poverty. Many studies have found that people living in poverty are more likely than others to become ill from pollution.

Data Resolution: 30m Raster

Data Units: percentile

Creation Method: CalEnviroScreen, Version 4.0, is a science-based method for identifying impacted communities by taking into consideration pollution exposure and its effects, as well as health and socioeconomic status, at the census-tract level. CalEnviroScreen 4.0 uses the census tract as the unit of analysis. Census tract boundaries are available from the Census Bureau. CalEnviroScreen uses the Bureau's 2010 boundaries. New boundaries will be drawn by the Census Bureau as part of the 2020 Census but will not be available until after 2022. OEHHA will address updates to census tract geography in CalEnviroScreen at that time. There are approximately 8,000 census tracts in California, representing a relatively fine scale of analysis. Census tracts are made up of multiple census blocks, which are the smallest geographic unit for which population data are available. Some census blocks have no people residing in them (unpopulated blocks).

The poverty percentile is derived from

- The 2015-2019 American Community Survey, a dataset containing the number of individuals below 200 percent of the federal poverty level was downloaded by census tracts for the state of California.
- The number of individuals below 200% of the poverty level was divided by the total population for whom poverty status was determined.
- Unlike the US Census, ACS estimates come from a sample of the population and may be unreliable if they are based on a small sample or population size. The standard error (SE) and relative standard error (RSE) were used to evaluate the reliability of each estimate.
- The SE was calculated for each census tract using the formula for approximating the SE of proportions provided by the ACS (American Community Survey Office, 2013, pg. 13, equation 4). CalEnviroScreen 4.0 189 When this approximation could not be used, the formula for approximating the SE of ratios (equation 3) was used instead.
- The RSE is calculated by dividing a tract's SE by its estimate of the percentage of the population living below twice the federal poverty level, and taking the absolute value of the result.
- Census tract estimates that met either of the following criteria were considered reliable and included in the analysis:
    - RSE less than 50 (meaning the SE was less than half of the estimate) OR
    - SE was less than the mean SE of all California census tract estimates for poverty.
- Census tracts with unreliable estimates received no score for the indicator (null). The indicator was not factored into that tract's overall CalEnviroScreen score.
- Census tracts that met the inclusion criteria were sorted and assigned percentiles based on their position in the distribution.

Data Source: California Environmental Protection Agency, CalEnviroScreen 4.0, CalEnviroScreen 4.0 | OEHHA

File Name: Poverty_Pctl.tif

HOUSING BURDEN PERCENTILE

Tier: 1

Data Vintage: 10/2021

Metric Definition and Relevance: Housing-Burdened Low-Income Households. Percent of households in a census tract that are both low income (making less than 80% of the HUD Area Median Family Income) and severely burdened by housing costs (paying greater than 50% of their income to housing costs). (5-year estimates, 2013-2017).

The cost and availability of housing is an important determinant of well-being. Households with lower incomes may spend a larger proportion of their income on housing. The inability of households to afford necessary non-housing goods after paying for shelter is known as housing-induced poverty. California has very high housing costs relative to much of the country, making it difficult for many to afford adequate housing. Within California, the cost of living varies significantly and is largely dependent on housing cost, availability, and demand.

Areas where low-income households may be stressed by high housing costs can be identified through the Housing and Urban Development (HUD) Comprehensive Housing Affordability Strategy (CHAS) data. We measure households earning less than 80% of HUD Area Median Family Income by county and paying greater than 50% of their income to housing costs. The indicator takes into account the regional cost of living for both homeowners and renters, and factors in the cost of utilities. CHAS data are calculated from US Census Bureau's American Community Survey (ACS).

Data Resolution: 30m Raster

Data Units: Percent

Creation Method: CalEnviroScreen, Version 4.0, is a science-based method for identifying impacted communities by taking into consideration pollution exposure and its effects, as well as health and socioeconomic status, at the census-tract level. CalEnviroScreen 4.0 uses the census tract as the unit of analysis. Census tract boundaries are available from the Census Bureau. CalEnviroScreen uses the Bureau's 2010 boundaries. New boundaries will be drawn by the Census Bureau as part of the 2020 Census but will not be available until 2022. OEHHA will address updates to census tract geography in CalEnviroScreen at that time. There are approximately 8,000 census tracts in California, representing a relatively fine scale of analysis. Census tracts are made up of multiple census blocks, which are the smallest geographic unit for which population data are available. Some census blocks have no people residing in them (unpopulated blocks).

The CalEnviroScreen model is based on the CalEPA working definition in that:

- The model is place-based and provides information for the entire State of California on a geographic basis. The geographic scale selected is intended to be useful for a wide range of decisions.
- The model is made up of multiple components cited in the above definition as contributors to cumulative impacts.
- The model includes two components representing Pollution Burden – Exposures and Environmental Effects
- The model includes two components representing Population Characteristics – Sensitive Populations (e.g., in terms of health status and age) and Socioeconomic Factors.

The American Community Survey (ACS) is an ongoing survey of the US population conducted by the US Census Bureau and has replaced the long form of the decennial census. Unlike the decennial census, which attempts to survey the entire population and collects a limited amount of information, the ACS releases results annually based on a sub-sample of the population and includes more detailed information on socioeconomic factors. Multiple years of data are pooled together to provide more reliable estimates for geographic areas with small population sizes. Each year, the HUD receives custom tabulations of ACS data from the US Census Bureau. These data, known as the "CHAS" data (Comprehensive Housing Affordability Strategy), demonstrate the extent of housing problems and housing needs, particularly for low-income households. The most recent results available at the census tract scale are the 5-year estimates for 2013-2017. The data are available from the HUD user website (see page 174 in the document link below:

https://oehha.ca.gov/media/downloads/calenviroscreen/report/calenviroscreen40reportf2021.pdf

Data Source: California Environmental Protection Agency, CalEnviroScreen 4.0

File Name: HousingBurdenPctl.tif

UNEMPLOYMENT PERCENTILE

Tier: 1

Data Vintage: 10/2021

Metric Definition and Relevance: Percentage of the population over the age of 16 that is unemployed and eligible for the labor force. Excludes retirees, students, homemakers, institutionalized persons except prisoners, those not looking for work, and military personnel on active duty (5-year estimate, 2015-2019).

Because low socioeconomic status often goes hand-in-hand with high unemployment, the rate of unemployment is a factor commonly used in describing disadvantaged communities. On an individual level, unemployment is a source of stress, which is implicated in poor health reported by residents of such communities. Lack of employment and resulting low income often constrain people to live in neighborhoods with higher levels of pollution and environmental degradation.

Data Resolution: 30m Raster

Data Units: Percent

Creation Method: CalEnviroScreen, Version 4.0, is a science-based method for identifying impacted communities by taking into consideration pollution exposure and its effects, as well as health and socioeconomic status, at the census-tract level. CalEnviroScreen 4.0 uses the census tract as the unit of analysis. Census tract boundaries are available from the Census Bureau. CalEnviroScreen uses the Bureau's 2010 boundaries. New boundaries will be drawn by the Census Bureau as part of the 2020 Census but will not be available until 2022. OEHHA will address updates to census tract geography in CalEnviroScreen at that time. There are approximately 8,000 census tracts in California, representing a relatively fine scale of analysis. Census tracts are made up of multiple census blocks, which are the smallest geographic unit for which population data are available. Some census blocks have no people residing in them (unpopulated blocks).

The CalEnviroScreen model is based on the CalEPA working definition in that:

- The model is place-based and provides information for the entire State of California on a geographic basis. The geographic scale selected is intended to be useful for a wide range of decisions.
- The model is made up of multiple components cited in the above definition as contributors to cumulative impacts.
- The model includes two components representing Pollution Burden – Exposures and Environmental Effects
- The model includes two components representing Population Characteristics – Sensitive Populations (e.g., in terms of health status and age) and Socioeconomic Factors.

The American Community Survey (ACS) is an ongoing survey of the US population conducted by the US Census Bureau. Unlike the decennial census, which attempts to survey the entire population and collects a limited amount of information, the ACS releases results annually based on a sub-sample of the population and includes more detailed information on socioeconomic factors such as unemployment. Multiple years of data are pooled together to provide more reliable estimates for geographic areas with small population sizes. The most recent results available at the census tract level are the 5-year estimates for 2015-2019. The data are made available using the U.S. Census data download website.

Data Source: California Environmental Protection Agency, CalEnviroScreen 4.0, CalEnviroScreen 4.0 | OEHHA

File Name: Unemployment_Pctl.tif

OPERATIONAL DATA LAYERS

In addition to the metric data layers assembled for this RRK project, a set of “operational” GIS data layers have been assembled to support use of the metrics. These data provide land use context (e.g. ownership, land use designations, background ecological information (e.g. climate refugia, stream locations, climate classes), infrastructure (roads, operational constraints, powerline corridors), and Forest Service policy information (spotted owl PACs, critical habitat maps for listed species, wilderness/roadless/wild and scenic rivers). These data are provided to assist managers in putting proposed treatments into context for what is feasible and what might constrain project planning.

Data layers provided within this designation of operational data are in their native projection and format with any embedded metadata maintained.

FIRE

RECENT FIRE SEVERITY CLASS

Data Vintage: 2012 - 2021

Metric Definition and Relevance: Fire severity classification (low, moderate, high) that burned within the last 10 years (2012-2021).

Data Resolution: 30m raster

Data Units: Value, 1 to 3

Creation Method: The difference-adjusted relativized difference normalized burn ratio (RdNBR) was calculated using methods modified from Parks et al (2018). Fire perimeters were obtained from CAL FIRE’s April 2021 fire perimeter database. A function for estimating basal area loss from RdNBR values was fit to data from Miller et al (2009) using quasibinomial logistic regression and applied to the 2012-2021 fires. Estimated basal area loss was thresholded to represent low (< 25% loss), moderate (25% – 75% loss), and high (> 75% loss) burn severity. For areas where multiple sequential fires burned from 2012-2021 the maximum burn severity is reported. Updated April 2023 to incorporate CAL FIRE’s October-2022 revisions to fire perimeters and to minimize data loss resulting from spatial reprojection.

- 1: Low Severity
- 2: Moderate Severity
- 3: High Severity

Data Source:

- Landsat 8, NASA
- Fire History (April 2022), CAL FIRE
- Postfire mortality data, Miller et al. 2009

File Name: fire_severity_class_max_2012to2021_all_CA_v2.tif

HOUSING UNIT DENSITY

Data Vintage: 01/2020

Metric Definition and Relevance: HUDen is a raster of housing-unit density measured in housing units per square kilometer. The HUDen raster was generated using population and housing-unit count and data from the U.S. Census Bureau, building footprint data from Microsoft, and land cover data from LANDFIRE.

Data Resolution: 30m Raster

Data Units: Housing units per square kilometer

Creation Method: Generate the HUDen raster from the building points. We first converted the building points to a 30-m raster where the raster value is the sum of the housing-units-per-centroid attribute of all building centroids within each raster grid cell. We then generated a smoothed density raster using a three-step process: 1) calculate a 200-m radius moving-window sum of the 30-m housing-unit count raster; 2) calculate a 200-m radius moving-window sum of habitable land cover (in sq km), where habitable land cover is all land covers except open water and permanent-snow/ice; and 3) divide the smoothed housing-unit count raster by the smoothed habitable land cover raster to generate housing unit density in housing units/sq km. To produce the final integer version of the HUDen raster, we set values less than 0.1 HU/sq km to zero, values between 0.1 and 1.5 to a value of 1 HU/sq km, and rounded all other values to the nearest integer.

Data Source: Pyrologix, LLC

File Name: HUden_2020.tif

WILDLAND URBAN INTERFACE

Data Vintage: 03/2022

Metric Definition and Relevance: The wildland urban interface (WUI) is the area where urban development is in close proximity to wildland vegetation. WUI data for the conterminous U.S. based on 125 million building locations where buildings intermingle with or abut wildland vegetation according to the Federal Register definitions of the WUI. According to the definitions used for our building-based maps and for the census-based maps, WUI is where building density exceeds 6.17 units/km2 and where land cover is either (1) at least 50% wildland vegetation (intermix) or (2) under 50% wildland vegetation but within 2.4 km (1.5 miles) of a patch of wildland vegetation at least 5 km2 in area that contains at least 75% vegetation (interface). The distance selected for the interface definition is based on research from the California Fire Alliance suggesting that this is the average distance firebrands can travel from an active wildfire front (Stewart et al., 2007).

Data Resolution: 30m Raster

Data Units: Categorical

Creation Method: Building point locations were obtained from a Microsoft product released in 2018, updated to 2019-2020 for most of California, which classified building footprints based on high-resolution satellite imagery. Maps were also based on wildland vegetation mapped by the 2016 National Land Cover Dataset (Yang et al., 2018). The mapping algorithm utilized definitions of the WUI from the U.S. Federal Register (USDA & USDI, 2001) and

Radeloff et al. (2005). Both classes required a minimum building density of 6.17 buildings per km2. This map of intermix and interface WUI was generated using a circular neighborhood size based on radius distance of 100m to determine building density and vegetation cover on a pixel-by-pixel basis (Bar Massada et al., 2013). Source: USGS ScienceBase Data Catalog; https://www.sciencebase.gov/catalog/item/617bfb43d34ea58c3c70038f

Values in the raster are defined as:

- 0: Not WUI
- 1: Intermix WUI
- 2: Interface WUI

Data Source: WUI, Carlson et al, 2022

File Name: MSB_WUI_CA_100m.tif

ADMINISTRATIVE

URBAN-AGRICULTURE LAND USE

Definition and Relevance: This dataset covers the urban and agricultural landscape for all forms of urban and agricultural land use in California. It was created using a combination of best available land cover data from multiple sources (see below). These data are used as a mask for selected metrics in the RRK project where inclusion of urban and agricultural cover potentially creates confusion in calculations of the metric.

Data Vintage: 06/2020

Data Resolution: Raster, 30m

Data Units: Thematic

Creation Method:

1. Farmland Mapping and Monitoring Program (FMMP) land-use data from 2018 was converted to 30m raster as the base input, using the values from the Type field of:

- Farmland of Statewide Importance
- Unique Farmland
- Farmland of Local Importance
- Urban and Built-Up Land
- Rural Residential Land
- Confined Animal Agriculture

2. Secondly, to bring more current data in, LANDFIRE 2020 Existing Vegetation Type (EVT) from 2020 was converted to 30m raster, using the values from EVT group name of:

    - Developed-Low Intensity
    - Developed-Medium Intensity
    - Developed-High Intensity
    - Agriculture-Cultivated Crops and Irrigated Agriculture

3. Lastly, [Building Footprints - Bing Maps (microsoft.com)](https://www.microsoft.com/en-us/maps/building-footprints) polygons were converted to 30m raster and added to the stack to include the most recent urban footprints.

Data Source:

Farmland Mapping and Monitoring Program (FMMP)
LANDFIRE: Existing Vegetation Type, U.S. Department of Agriculture and U.S. Department of the Interior
MS Building Footprints

File Name: UrbanAgLanduse_RRK_2020.tif

BUILDING STRUCTURE DENSITY

Definition and Relevance: A raster dataset containing building footprints of California. The vintage of the footprints depends on the vintage of the underlying imagery. Bing Imagery is a composite of multiple sources with different capture dates.

Data Vintage: 2012-2020.

Data Resolution: Raster, 10m

Data Units: binary

Creation Method: Vector spatial data called US Building Footprints contained in a Microsoft dataset (available at https://github.com/microsoft/USBuildingFootprints) downloaded, clipped to California and converted to a 10m raster. For more information visit: Building Footprints - Bing Maps (microsoft.com)

Data Source: MS Building Footprints

File Name: CA_bldgFootprints_10m.tif

HIGH-USE RECREATION AREAS

Definition and Relevance: A recreation site is a discrete area on a National Forest that provides recreation opportunities, receives recreational use, and requires a management investment to operate and/or maintain to standard under the direction of an administrative unit in the National Forest System. Recreation sites range in development from relatively undeveloped areas, with little to no improvements (Development Scale 0 and 1), to concentrations of facilities and services evidencing a range of amenities and investment (Development Scale 2 through 5).

Recreation opportunities are point locations of recreational site activities available to visitors and populates the Forest Service websites (https://www.fs.usda.gov/), and the interactive visitor map (https://www.fs.usda.gov/ivm/).

Data Vintage: 01/2023

Data Resolution: Points

Data Units: Tabular attributes

Creation Method: see Metadata

Data Source: USFS Enterprise Data Warehouse (EDW)

File Name: RECAREAACTIVITIES_V_2023.shp

LAND DESIGNATIONS

Definition and Relevance: Wilderness, Roadless, Wild and Scenic River

Data Vintage: 01/2023

Data Resolution: ArcGIS file geodatabase: Vector, polygon

Data Units: Tabular attributes

Creation Method: Data layers pulled from the Enterprise Data Warehouse for land designations:

- *Wilderness* – area designated as a National Wilderness in the National Wilderness Preservation System
- *Inventoried Roadless Areas* – the 2001 Roadless Rule establishes prohibitions on road construction, road reconstruction, and timber harvesting on inventoried roadless areas on National Forest System lands by the following classifications:
    - 1B = Inventoried Roadless Areas where road construction and reconstruction is prohibited
    - 1B-1 = Inventoried Roadless Areas that are recommended for wilderness designation in the forest plan and where road construction and reconstruction is prohibited
    - 1C = Inventoried Roadless Areas where road construction and reconstruction is not prohibited
- *Wild and Scenic Rivers* – area designated as a National Wild, Scenic, or Recreational River within the National Wild and Scenic River System. The designations and definitions are:
    - Wild (W) – Those rivers or sections of rivers that are free of impoundments and generally inaccessible except by trail, with watersheds or shorelines essentially primitive and waters unpolluted. These represent vestiges of primitive America.
    - Scenic (S) – Those rivers or sections of rivers that are free of impoundments, with shorelines or watersheds still largely primitive and shorelines largely undeveloped, but accessible in places by roads.
    - Recreational (R) – Those rivers or sections of rivers that are readily accessible by road or railroad, that may have some development along their shorelines, and that may have undergone some impoundment or diversion in the past.

Data Source: USFS Enterprise Data Warehouse (EDW)

File Name: Wilderness_2023.shp; Roadless_2001.shp; WildScenicRiver_2023.shp

OWNERSHIP

Definition and Relevance: Ownership is a commonly used base layer used in a wide range of business functions and these data are intended to provide a depiction of the land ownership within the RRK project area.

Data Vintage: FS_BasicOwnership: 01/2023, ownership: 05/2022

Data Resolution: Vector, polygon

Data Units: Tabular attributes

Creation Method:

- *FS_BasicOwnership_2023.shp* – an area depicted as surface ownership parcels dissolved on the same ownership classification administered by the USDA Forest Service (USFS).

- *ownership22_1* – California Multi-Source Land Ownership, includes lands owned by each federal agency (including USFS), state agency, local government entities, conservation organizations, and special districts. It does not include lands of private ownership.

Data Source: USDA Forest Service, CAL FIRE

File Name: FS_BasicOwnership_2023.shp; ownership22_1.shp

ROADS

Definition and Relevance: This California statewide dataset was downloaded from Geofabrik's free download server for California. This server has data extracts from the OpenStreetMap project which are normally updated every day.

Data Vintage: 09/2022

Data Resolution: Vector, line

Data Units: Tabular attributes

Creation Method: To simplify the layer, major roads were exported with the following selection of the attribute "fclass":

- 5111 = motorway
- 5112 = trunk
- 5113 = primary
- 5114 = secondary
- 5121 = unclassified
- 5122 = residential
- 5123 = living street

Data Source: Open Street Map roads based on Tiger Lines (OSM)

File Name: OSM_majorRoads_CA_2022.shp

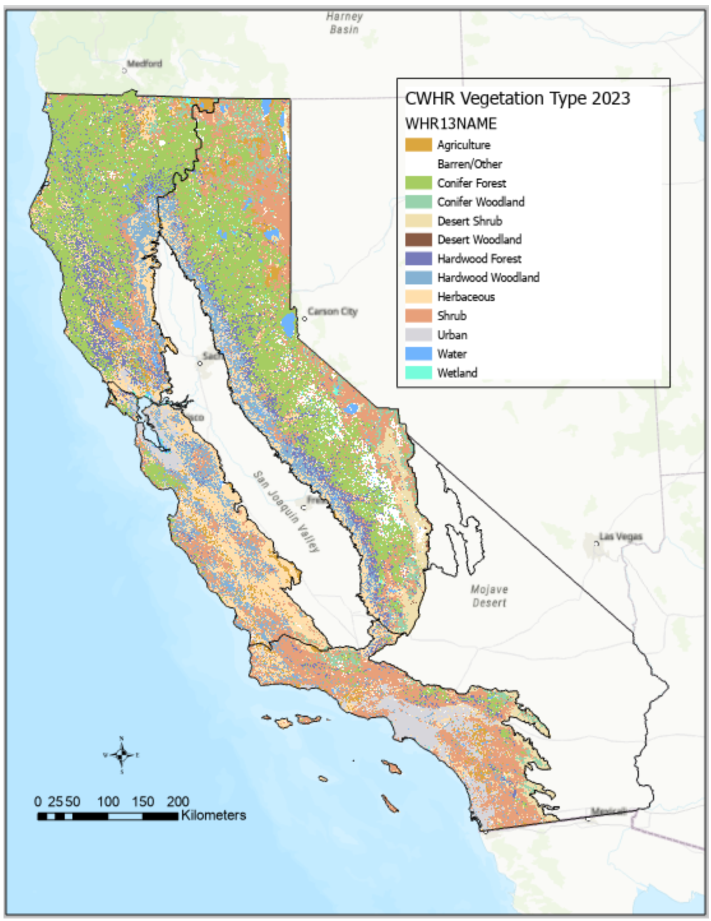
TERRESTRIAL

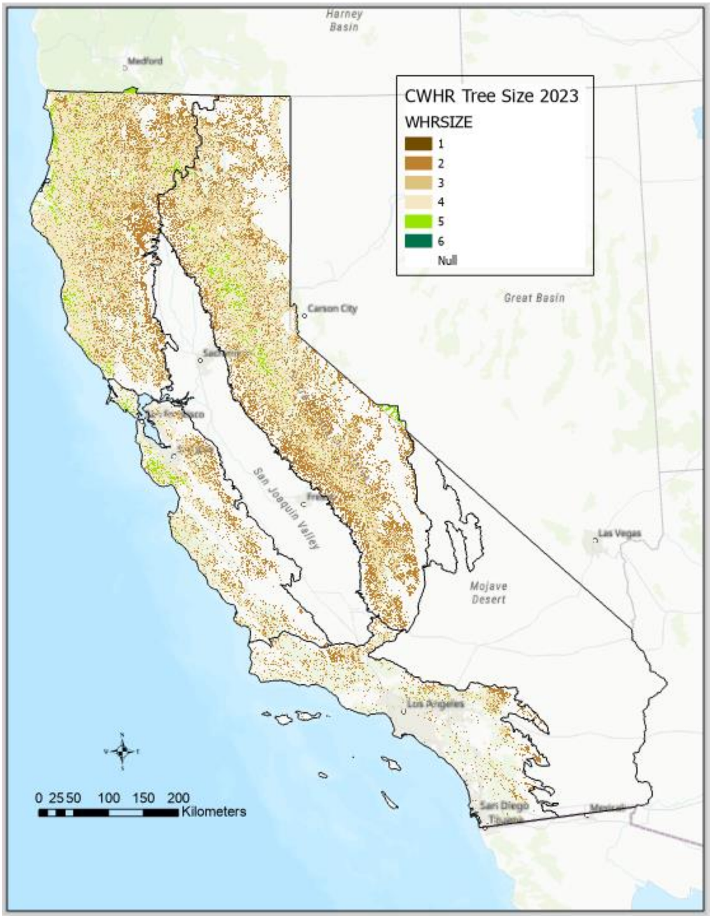
CWHR VEGETATION

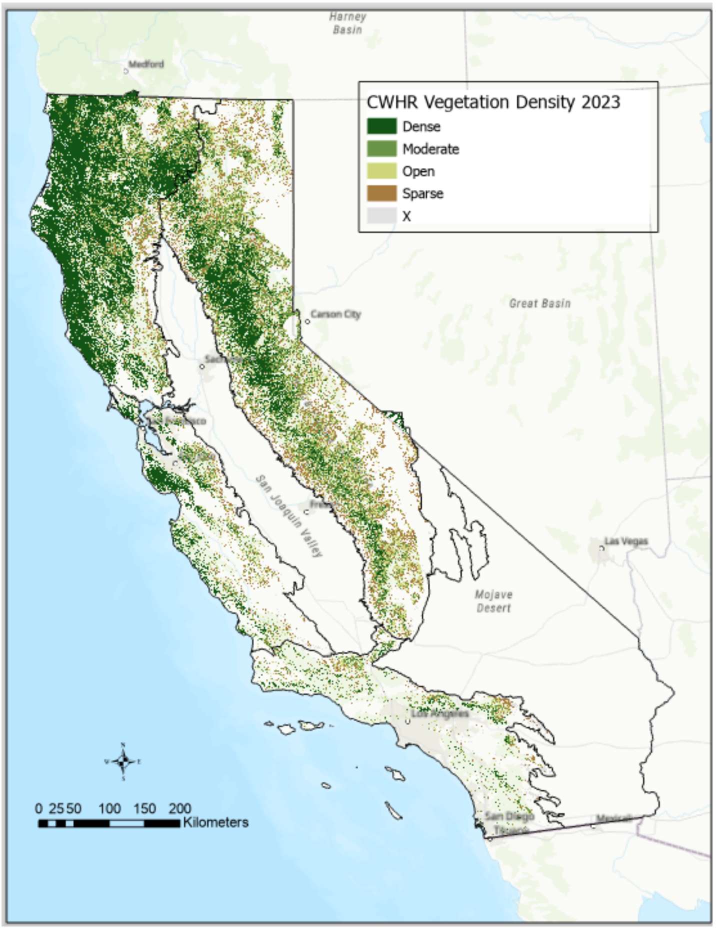
Vegetation maps play a vital role in characterizing conditions for many metrics. We need high resolution details on vegetation composition and structure; a vegetation classification, mapping, and inventory processes that provides vegetation information for a wide variety of metrics. The broader land management community continues to develop such products and make incremental improvements.

The current version displayed here is a new iteration of the FVeg. This is a product of CALFIRE-FRAP, which compiles the "best available" land cover data into a single data layer, to support the various analyses required for the Forest and Rangeland Assessment. Fveg attempts to provide an accurate depiction of the spatial distribution of habitat types within California, required for a variety of legislatively-mandated government functions. This is a product of the California Department of Forestry and Fire Protections CALFIRE Fire and Resource Assessment Program (FRAP), in cooperation with California Department of Fish and Wildlife VegCamp program and extensive use of USDA Forest Service Region 5 Mapping and Remote Sensing (MARS). The data span a period from approximately 1990 to 2014. Typically the most current, detailed and consistent data were collected for various regions of the state. Decision rules were developed that controlled which layers were given priority in areas of overlap. Cross-walks were used to compile the various sources into the common classification scheme, the California Wildlife Habitat Relationships (CWHR) system.

This iteration of Fveg has been updated as explained below. It only covers the four regions of the RRKs that have been mapped and only within the state of California. There are issues with the data in the portions of the map that extend into Nevada. This continues to be a work in progress where we hope to make improvements in the future. There are three separate rasters provided; one for CWHR Vegetation Type, one for CWHR Tree Size Class, and one for CWHR Veg Canopy Cover (Density) Class.




CWHR Tree Size 2023
WHRSIZE
1
2
3
4
5
6
Null
Harney Basin
Medford
Carson City
Great Basin
San Joaquin Valley
Las Vegas
Mojave Desert
Los Angeles
San Diego
0 25 50 100 150 200
Kilometers



Definition and Relevance: Vegetation maps are important for characterizing many important features of a landscape such as wildlife habitat, fuels conditions, forest composition, and carbon. Such data are most useful if they can depict vegetation type, cover, and tree size class. This version was created to capture current conditions as best as possible through a variety of existing and current sources. Cross-walks were used to compile the various sources into the common classification scheme, the California Wildlife Habitat Relationships (CWHR) system. See CWHR for more details on the CWHR system (California Wildlife Habitat Relationships).

Key field names in this data set (there are others) are defined as follows:

WHRALL - Unique habitat data label. Concatenated from separate habitat attributes WHRtype, WHRsize and WHRdensity.

WHRNUM - Unique number for each Wildlife Habitat Relationship class (WHRtype).

WHRNAME - Unique name for each Wildlife Habitat Relationship class (WHRtype)

WHRTYPE - Unique Wildlife Habitat Relationship (WHR) class code

WHRSIZE - Wildlife Habitat Relationship Size Class (tree types only)

WHRDENSITY - Wildlife Habitat Relationship class (tree types only)

SOURCE_NAME - General description of where the source data layer used for a given geography

SOURCE_YEAR - Year of base imagery that source data layer references for a given geography

WHR Codes for Vegetation Types:

Tree Dominated Habitats

CWHR Code	Type Description
ASP	Aspen
BOP	Blue Oak-Foothill Pine
BOW	Blue Oak Woodland
COW	Coastal Oak Woodland
CPC	Closed-Cone Pine-Cypress
DFR	Douglas Fir
DRI	Desert Riparian
EPN	Eastside Pine
EUC	Eucalyptus
JPN	Jeffrey Pine
JST	Joshua Tree
JUN	Juniper
KMC	Klamath Mixed Conifer
LPN	Lodgepole Pine
MHC	Montane Hardwood-Conifer
MHW	Montane Hardwood
MRI	Montane Riparian
PJN	Pinyon-Juniper

POS	Palm Oasis
PPN	Ponderosa Pine
RDW	Redwood
RFR	Red fir
SCN	Subalpine Conifer
SMC	Sierran Mixed Conifer
VOW	Valley Oak Woodland
VRI	Valley Foothill Riparian
WFR	White fir

Shrub Dominated Habitats

CWHR Code	Type Description
ADS	Alpine Dwarf-Shrub
ASC	Alkali Desert Scrub
BBR	Bitterbrush
CRC	Chamise-Redshank Chaparral
CSC	Coastal Scrub
DSC	Desert Scrub
DSS	Desert Succulent Shrub
DSW	Desert Wash
LSG	Low Sage
MCH	Mixed Chaparral
MCP	Montane Chaparral

SGB	Sagebrush

Herbaceous Dominated Habitats

CWHR Code	Type Description
AGS	Annual Grass
FEW	Fresh Emergent Wetland
PAS	Pasture
PGS	Perennial Grass
SEW	Saline Emergent Wetland
WTM	Wet Meadow

Aquatic Habitats

CWHR Code	Type Description
EST	Estuarine
LAC	Lacustrine
MAR	Marine
RIV	Riverine

Developed Habitats

CWHR Code	Type Description
CRP	Cropland
DGR	Dryland Grain Crops
DOR	Deciduous Orchard

EOR	Evergreen Orchard
IGR	Irrigated Grain Crops
IRF	Irrigated Row and Field Crops
IRH	Irrigated Hayfield
OVN	Orchard - Vineyard
RIC	Rice
URB	Urban
VIN	Vineyard

Non-vegetated Habitats

CWHR Code	Type Description
BAR	Barren

WHR Codes for Tree Size Classes:

CWHR Code	CWHR Size Class	Conifer Crown Diameter	Hardwood Crown Diameter	DBH
1	Seedling tree	n/a	n/a	<1.0"
2	Sapling tree	n/a	<15.0'	1.0" - 5.9"
3	Pole tree	<12.0'	15.0' - 29.9'	6.0" - 10.9"
4	Small tree	12.0' - 23.9'	30.0' - 44.9'	11.0" - 23.9"
5	Medium/large tree	≥24.0'	≥45.0'	≥24.0"
6	Multi-layered tree	A distinct layer of size class 5 trees over a distinct layer of size class 4 and/or 3 trees, and total tree canopy of the layers ≥60% (layers must have ≥10.0% canopy cover and distinctive height separation).		

WHR Codes for Density Classes:

WHR Code	CWHR Closure Class	Vegetation Cover (Canopy Closure)
S	Sparse Cover	10.0 - 24.9%
P	Open Cover	25.0 - 39.9%
M	Moderate Cover	40.0 - 59.9%
D	Dense Cover	≥60%
X	Not Determined / Not Applicable	

Data Vintage: 04/2023

Data Resolution: Raster, 30 meter pixels

Data Units: Categorical (see above)

Creation Method: Vegetation maps are an important feature of any natural resource management portfolio. Currently the vegetation map for the entire state that is considered the "best available" data is the CALFIRE data known as FVEG (*Vegetation (fveg) - CALFIRE FRAP [ds1327]*). This is an excerpt from the metadata:

“The California Department of Forestry and Fire Protections CALFIRE Fire and Resource Assessment Program (FRAP), in cooperation with California Department of Fish and Wildlife VegCamp program and extensive use of USDA Forest Service Region 5 Remote Sensing Laboratory (RSL) *[now known as Mapping and Remote Sensing Team (MARS)]*, has compiled the "best available" land cover data available for California into a single comprehensive statewide data set. The data span a period from approximately 1990 to 2014. Cross-walks were used to compile the various sources into the common classification scheme, the California Wildlife Habitat Relationships (CWHR) system.”

Given the degree of fire in Central Coast in the last 30 plus years, especially in areas that experienced high severity fire, our RRK team thought that using the last version of FVEG (from 2015 but source data could be as old as 1987) would have too many glaring errors. Notwithstanding the challenge of creating reliable vegetation maps, we thought it would be possible to make improvements over the most recent map.

There are many avenues for improving vegetation maps. However, we did not have time to build anything from a new starting point, so we constructed a few simple rules for making updates to the FVEG data layer.

There are three separate rasters provided; one for CWHR Vegetation Type, one for CWHR Tree Size Class, and one for CWHR Veg Canopy Cover (Density) Class.

The sources for updated data include:

- Fire severity data (from CALFIRE)

· LANDFIRE 2021 land cover data (wildland fire management programs of the USDA Forest Service and USDI)

· Herbaceous cover (Region 5 MARS Team)

· California Forest Observatory (SALO)

Updated FVEG; Methods for 2023 statewide updates to FVEG WHRtype, WHRsize, and WHRdensity

An accurate depiction of the spatial distribution of vegetation/habitat types within California is required for a number of the metrics included in this kit, particularly for some of the fire, forest and rangeland resiliency, and biodiversity metrics . The California Department of Forestry and Fire Protections CALFIRE Fire and Resource Assessment Program (FRAP), in cooperation with California Department of Fish and Wildlife VegCamp program and extensive use of USDA Forest Service Region 5 Mapping and Remote Sensing unit (MARS) data, has compiled the "best available" land cover data available for California into a single comprehensive statewide data set. The data span a period from approximately 1990 to 2014.

Because the source data are in many cases fairly old and there has been extensive disturbance, particularly from wildfire, over the last 25 years, we made some updates to the 2015 version of FVEG. The methods for making those changes are described here.

WHRtype update

FVEG's WHRtype was updated with the LANDFIRE Existing Vegetation Type (EVT) data product version 2.2.0 (LANDFIRE 2020) and the Rangeland Analysis Platform (RAP) fractional ground cover data product version 3.0 (Jones et al. 2018, Allred et al. 2021). Pixels were considered for update where high severity wildfire occurred after the FVEG mapping date. High severity was defined as wildfire burned areas that experienced ≥75% loss in basal area (Parks et al. 2018, Young-Hart et al. 2022) following the wildfire event. The type of update that occurred in each "high severity" pixel was dependent upon a lifeform conversion comparison (FVEG-to-LANDFIRE EVT), vegetation height (SALO 2020), and percent ground cover by annual and perennial grasses (RAP) (Table 1).

Table 1. FVEG-LANDFIRE update type for high severity pixels. Annual grass (AG) cover and perennial grass (PG) cover data were from the Rangeland Analysis Platform fractional ground cover data product version 3.0. Canopy height (CH) data were from the SALO forest observatory data product.

	FVEG Lifeform			
		Herbaceous	*Shrub*	*Tree*
LANDFIRE EVT Lifeform	*Herbaceous*	• Where AG cover >50%, update to "Annual Grassland" WHRname ("AGS" WHRtype)	• Where CH <1m & AG cover >50%, update to "Annual Grassland" WHRname ("AGS" WHRtype)	• Where CH <2m & AG cover >50%, update to "Annual Grassland" WHRname ("AGS" WHRtype)
		• Where PG cover >50%, update to "Perennial Grassland" WHRname ("PGS" WHRtype)	• Where CH <1m & PG cover >50%, update to "Perennial Grassland" WHRname ("PGS" WHRtype)	• Where CH <2m & PG cover >50%, update to "Perennial Grassland" WHRname ("PGS" WHRtype)
		• Otherwise, no update to WHRtype	• Otherwise, FVEG-LANDFIRE crosswalk update	• Otherwise, FVEG-LANDFIRE crosswalk update
	Shrub	FVEG-LANDFIRE crosswalk update	No update to WHRtype	FVEG-LANDFIRE crosswalk update
	Tree	FVEG-LANDFIRE crosswalk update	• FVEG-LANDFIRE crosswalk update	No update to WHRtype

WHRdensity and WHRsize updates

Following the WHRtype update, pixels that had lifeform "tree" then had the FVEG attributes "WHRdensity" and "WHRsize" updated using the SALO Forest Observatory canopy height and canopy cover data products (SALO 2020). SALO data were available for the years 2016-2020, values of canopy height and canopy cover were averaged across years for the update[2] .

To update WHRdensity, SALO canopy cover was converted to WHRdensity canopy closure class per the Wildlife Habitat Relationships, Standards for Canopy Closure Table 114C.

To update WHRsize, we developed allometric equations that predict tree DBH (diameter at breast height, breast height = 4.5 ft) as a function of tree height (HT, ft). We used data from the USDA Forest Inventory and Analysis program (FIA) for California (FIA DataMart 2023; California 2022 database; ver. 9.0.1). For this analysis, we included live trees ≥ 4.5 ft tall with a crown class code of dominant, co-dominant, or open grown (N = 165,224 tree measurements between 1991 and 2019). Trees were grouped by region based on the "fuzzed" location of the plot. Regions were defined by the Regional Resource Kits (2023, 4 regions) and separated into softwoods and hardwoods as defined by FIA (2 categories). For each analysis, three functions were evaluated: linear, saturating, and power:

Linear: DBH = a + (b*HT);

Saturating (Michaelis–Menten): DBH = (Vm*HT)/(K+HT);

Power: DBH = aHT^b.

For the most informative model (i.e., lowest AIC), we report both the root mean squared error (RMSE) and the pseudo R^2. In this case, pseudo R^2 was calculated as the coefficient of determination between the observed and predicted DBHs (Table 2). We used the most informative HT-to- DBH function for the region and tree category to convert SALO canopy height data to DBH that was then converted to WHRsize class per the [Wildlife Habitat Relationships, Standards for Tree Size Table 114B.]()

Table 2. Height-to-DBH conversion equations by California region and tree class. DBH is in inches; Height (HT) is in feet. Only included trees with a HT > = 4.5 feet. Only included canopy class = dominant, co-dominant, or open. Equation (EQN) code: MM = Michaelis Menton; POWER = power; Linear = linear.

Region	**Tree Class**	**EQN**	**a (Vm)**	**b (K)**	**RMSE**	**pseudoR^2**	**EQN formula**
Sierra Nevada	Softwood	MM	223.39	712.20	6.57	0.69	DBH= (Vm*HT)/(K+HT)
Sierra Nevada	Hardwood	Linear	-0.391	0.294	4.69	0.57	DBH= a+b(HT)
Southern California	Softwood	MM	108.97	216.30	7.47	0.55	DBH = (Vm*HT)/(K+HT)
Southern California	Hardwood	MM	175.17	424.31	5.55	0.52	DBH = (Vm*HT)/(K+HT)
North Coast	Softwood	POWER	0.128	1.13	6.51	0.74	DBH = a*HT^b
North Coast	Hardwood	Linear	0.135	0.242	5.2	0.49	DBH = a+b(HT)
Central Coast	Softwood	Linear	0.588	0.244	8.25	0.62	DBH = a+b(HT)
Central Coast	Hardwood	MM	68.51	161.40	6.24	0.45	DBH = (Vm*HT)/(K+HT)

Availability of Data and Materials

Data used for the 2023 FVEG updates can be obtained from the following:

- LANDFIRE – http://www.landfire.gov/

- Rangeland Analysis Platform – https://rangelands.app/products/
- SALO Forest Canopy – https://forestobservatory.com/download
- 10-year summary of basal area lost – https://data.fs.usda.gov/geodata/rastergateway/acre
- Perturbed FIA data – https://experience.arcgis.com/experience/3641cea45d614ab88791aef54f3a1849

Google Earth Engine Python API script can be obtained from: https://github.com/kjohnston73/fveg_update

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Data Source: CALFIRE, CDFW, LANDFIRE, California Forest Observatory (SALO), USDA Forest Service

File Name: RRK_Fveg_WHRtype_2023Apr_4regions_v2.tif; RRK_Fveg_WHRsize_2023Apr_4regions.tif; RRK_Fveg_WHRDensity_2023Apr_4regions.tif

AQUATIC

LAKES/RESERVOIRS

Definition and Relevance: Water Bodies such as lake and reservoir features are represented in this layer pulled from the National Hydrography Dataset (NHD). These data were used to erase areas of lakes and ponds from every raster metric in the RRK project dataset.

Data Vintage: 12/2022

Data Resolution: 30m Raster

Data Units: Binary, 0/1

Creation Method: This dataset is a subset of vector polygon NHD water bodies, encompassing the RRK project boundary and converted to a raster grid at 30m resolution based on existence/non-existence.

Data Source: USGS National Hydrography Dataset (NHD); https://www.usgs.gov/national-hydrography/national-hydrography-dataset

File Name: NHD_lakesReservoirs_2022_RRK.tif

PERENNIAL AND INTERMITTENT STREAMS

Definition and Relevance: USGS National Hydrography Dataset (NHD); Flowline is the fundamental flow network consisting predominantly of stream/river and artificial path vector features. It represents the spatial geometry and carries the attributes

Data Vintage: 12/2022

Data Resolution: Vector, line

Data Units: Tabular attributes

Creation Method: Data selected from NHD Flowline feature class to contain only FType code 460, StreamRiver (Perennial, Intermittent) for the state of California.

Data Source: USGS National Hydrography Dataset (NHD); https://www.usgs.gov/national-hydrography/national-hydrography-dataset

File Name: NHD_Stream_2022.tif

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ADDITIONAL RESOURCES

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Connecting Wildlands & Communities, Conservation Ecology Lab - San Diego State University. Connecting Wildlands & Communities | Climate Science Alliance

Monitoring Trends in Burn Severity (MTBS) program: https://www.mtbs.gov/

Multi-Resolution Land Characteristics Consortium (MRLC): https://www.mrlc.gov/

Oregon State University Environmental Monitoring, Analysis, and Process Recognition (eMapR) Lab: http://emapr.ceoas.oregonstate.edu/

Rapid Assessment of Vegetation Condition after Wildfire (RAVG): https://burnseverity.cr.usgs.gov/ravg/

Spatial Informatics Group: Home - SIG (sig-gis.com)

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