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Lake Tahoe West
Landscape Resilience Assessment

Version 1

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This document is the Lake Tahoe West Landscape Resilience Assessment Version 1, a product resulting from the first phase of the Lake Tahoe West Restoration Partnership (https://www.nationalforests.org/who-we-are/regional-offices/california-program/laketahoewest). The assessment was developed through a highly collaborative process with a diverse group of stakeholders from a variety of organizations with complementary expertise. The assessment used the best available data to describe the current condition of the natural environment of the west side of the Lake Tahoe Basin, and the resilience of those environmental characteristics, values, and ecosystem services to a variety of disturbances.

This first version of the Landscape Resilience Assessment will be used to inform Phase 2 of the Lake Tahoe West project, which will evaluate strategies to restore or maintain resilience on the west shore, and locations within which to conduct restoration activities. The assessment is not a stand-alone project planning or prioritization tool; it is intended to be used in combination with other tools such as science modeling, expert judgement, and stakeholder input. The Assessment will be refined once, at the end of Phase 2, using the results of science modeling to fill in critical data gaps or improve the data used in the assessment. The Assessment is not a living document and will be finalized during Lake Tahoe West Phase 2, but the framework is intended to inform future landscape scale restoration efforts.

Executive Summary

The Landscape Resilience Assessment evaluated the current condition of the natural environment of the west side of the Lake Tahoe Basin and the resilience of those environmental characteristics, values and ecosystem services to a variety of disturbances. Through an iterative process, with stakeholder and scientist input, the Interagency Design Team selected ecological and sociological landscape values and services, and primary disturbances that are important to understand the current state of resilience of the west shore. Using the best available quantitative and spatially-explicit data, the Design Team compared current conditions to historic and/or contemporary reference conditions to determine which portions of the landscape and which landscape values and services are the least resilient to disturbances.

The results indicate that much of the Lake Tahoe Basin's west shore, one of America's most iconic landscapes, is likely not resilient to a variety of disturbances. The west shore's aquatic and terrestrial systems are in need of more intensive restoration efforts across the broader landscape (in addition to the areas near communities), as demonstrated by the results of the assessment. The following are highlights of findings with implicit management implications:

- Over 75% of the Lake Tahoe west shore is highly departed from pre Euro-American settlement fire return intervals. Higher elevation areas show less fire interval departure than relative lower elevation areas. These areas may have higher fuel loading, which makes them more susceptible to catastrophic fire, and have a higher density of trees, which makes them more vulnerable to drought and insects & disease.
- When a fire starts on the west shore, one third of the area is susceptible to large patches of high severity fire. The most susceptible locations include: Blackwood and Ward canyons, Truckee River and General Creek drainages, and upland areas in the vicinity of Tahoe City and Emerald Bay. Previous restorative investments in the Lake Tahoe Basin have been concentrated in the area of highest need (Wildland Urban Interface), but more work is needed, and reinvestment in previously treated areas is essential to improve and maintain the efficacy of the treatments.
- Mid-seral forests are over represented in the vast majority (87%) of the west shore and late seral stages (e.g., old growth) are underrepresented. There are more trees per acre than historic or contemporary reference conditions, and during droughts, vegetation is stressed for water. This lack of forest stage diversity, high tree densities, and stressed vegetation conditions decreases the resilience of the forested system to many disturbance types (e.g., fire, drought, insect & disease) and may impact the quality and quantity of wildlife habitat.
- Forested areas on the landscape are less patchy and more homogenous than reference conditions, making them less resilient to disturbances including fire and insects & disease.
- Within forest stands, when compared to reference conditions, there is an over representation of stands with vegetation loaded near the ground, creating high levels of ladder fuels that reduces resilience to fire and may impact the quality and quantity of wildlife habitat.
- Approximately two thirds of the meadows in the west shore are not believed to be able to provide adequate refugia for meadow species under future climate scenarios.
- Eighty percent of streams in the west shore have barriers to aquatic organism passage and nearly half (47%) of the streams contain more non-native than native aquatic species.

- Three-quarters of the west shore landscape is within a quarter mile of a road or trail, indicating that the majority of the west shore of Lake Tahoe is influenced by human presence.
- Higher elevations and wilderness areas are more resilient to most disturbances, whereas canyons and lower elevations are especially vulnerable to impacts associated with fire, drought, and climate change. Restoration activities focused in these areas may maximize landscape resilience.

Contents

Authors and Affiliations

Shana Gross, Central Sierra Province Associate Ecologist, Forest Service Pacific Southwest Region

Mason Bindl, GIS Analyst, Tahoe Regional Planning Agency

Jen Greenberg, Environmental Planner, California Tahoe Conservancy

Forest Schafer, Incident Commander, Tahoe Fire and Fuels Team

Stephanie Coppeto, Wildlife Biologist, Forest Service Lake Tahoe Basin Management Unit

Nadia Tase, Climate Change and Forest Inventory Specialist, California Department of Forestry and Fire Protection

Brian Garrett, Assistant Staff Officer, Vegetation Management Program, Forest Service Lake Tahoe Basin Management Unit

Randy Striplin, Fire Planner, Forest Service Lake Tahoe Basin Management Unit

Dan Shaw, Environmental Scientist, California State Parks

Whitney Brennan, Wildlife Biologist, California Tahoe Conservancy

Mike Vollmer, Environmental Improvement Program Manager, Tahoe Regional Planning Agency

Dorian Fougères, Collaborative Science and Planning Specialist, California Tahoe Conservancy

Sarah Di Vittorio, Northern California Program Manager, National Forest Foundation

Jason Vasques, Recreation, Access, and Forest Ecosystem Planning Supervisor, California Tahoe Conservancy

Introduction

There are seven broad phases of the Lake Tahoe West (LTW) project (Figure 1). Phase 1 is the development of the Landscape Resilience Assessment which is intended to evaluate the current state of resilience of various landscape values and services to primary disturbances, and identify a resilient condition for these values and services. The term “resilience” is used to signify the “capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks” (Walker et al. 2004).

It is important that the term “disturbance” should not be viewed with a negative lens. Ecological disturbance processes (e.g., fire, flood, drought, insects and disease, erosion) are processes that structure and maintain an ecosystem. However, external factors, e.g., fire suppression, human caused ground disturbance, can cause these disturbance processes to operate in ways that produce extreme disturbance effects that are inconsistent with the expected disturbance regime. Whether a disturbance process is beneficial or detrimental depends completely on how it occurs – its geographic extent, intensity, duration, and frequency. Desired resilient conditions may therefore aim for a given range of disturbance that would bolster system resilience, and seek to avoid a deficiency or excess of disturbance that would erode resilience.

There are multiple historic accounts that document the excess of disturbance due to logging during the Comstock Era (1870-1890) (e.g. Sudworth 1900). Historical accounts evoke a largely denuded landscape where most trees of any size were clear-cut. The US Forest Service and other public land management agencies worked to acquire these disturbed areas throughout the 20th century in order to bring the forested landscape back- with a look towards the future. Regulatory agencies, private interests, residents, visitors, and scientists have been profoundly invested in this recovery process. In this context, it is important to understand that the process of recovery is slow, especially for a forested landscape that was dominated by large trees that were centuries old. It may be difficult to tell now how altered the Basin was in the not too distant past, but recovery and restoration of these lands remains a challenging, essential, and ongoing task towards a resilient landscape, both socially and ecologically.

With the exception of areas where people live and have associated structures, the Landscape Resilience Assessment prioritizes conditions that would restore (or maintain) the resilience of the west shore’s upland, aquatic, and meadow and riparian ecosystems. The Design Team recognizes that protecting life and property will remain the priority in and around human communities, and that desired conditions will vary accordingly from the rest of the landscape. In this regard, the Resilience Assessment is the most flexible, visionary phase of Lake Tahoe West.

Developing this document involved the following five steps through an iterative process among the Interagency Design Team and Stakeholder Science Committee, with input from other groups such as the Stakeholder Community Committee and the Science Team:

1. identifying landscape values and services to be resilient to major disturbances,
2. identifying indicators of resilience,
3. specifying a range of resilient conditions for each indicator,
4. analyzing geospatial data for each indicator to determine current resilience, and
5. combining multiple indicators into composite indicators to identify resilience to a disturbance and resilience of a value/service.

The Landscape Resilience Assessment will be used to inform Phase 2, the Landscape Restoration Strategy, which will also, in turn, inform refinements of this Assessment. During Phase 2, the Design Team, working with stakeholder input, will evaluate strategies to restore/maintain resilience on the west shore and locations within which to conduct restoration activities or areas that are suitable for no active management. Some restoration activities may include no action at all, or passive management such as use of managed wildfire. Focused and targeted modeling by the Science Team will be used to verify and refine the Landscape Restoration Strategy. See Figure 1 for a graphic depiction of the seven phases of LTW and the feedback loops among those phases.

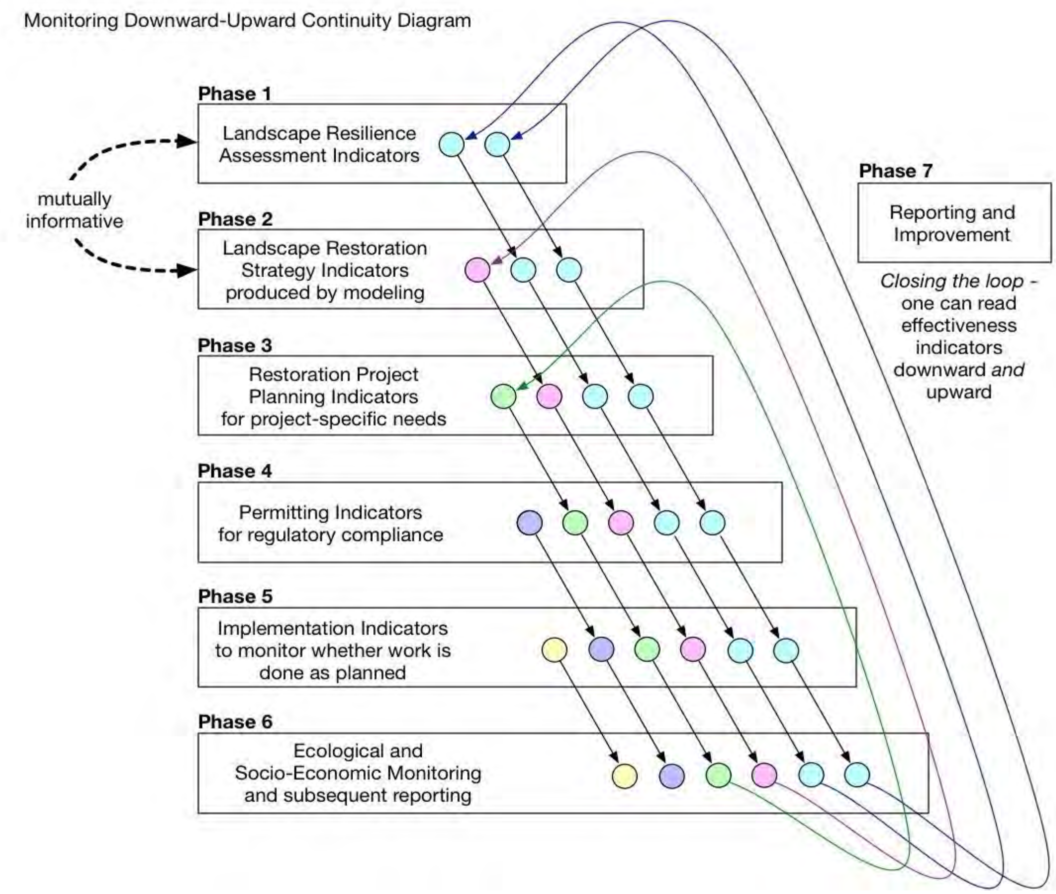

Figure 1. The seven phases of the LTW project and feedback loops among those phases. Note that this document is version 1 of the Landscape Resilience Assessment developed during Phase 1.

The Resilience Assessment represents a period of broad and unencumbered thinking. Lake Tahoe West expects that this visionary thinking associated with Phase 1 (assessment) will be slightly more constrained in Phases 2 (strategy development) and 3 (project planning). Phase 2 will acknowledge the landscape-scale constraints. Phase 3 will have to work through the range of fine-scale constraints on management activities that are codified in agency standards, guidelines, and regulations. Additionally, organizational capacity and funding may further constrain actions.

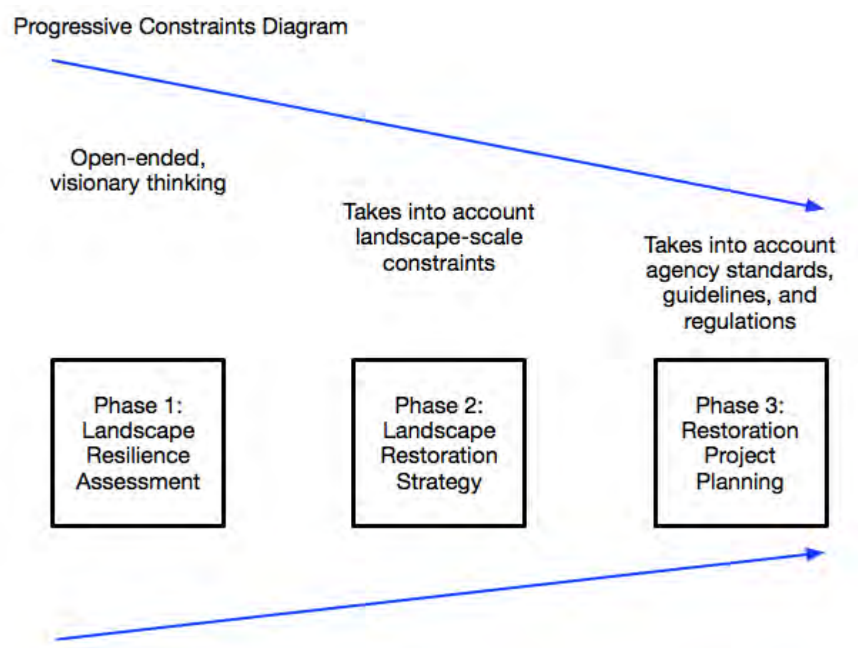

Figure 2. Progressive constraints from Phase 1 to Phase 3 of the LTW project, indicating the refinement needed as LTW moves further along in the development of the project.

Methods

Below is a summary of the methods used to assign a resilient condition to the various indicators selected and a description of the indicator itself. This section also provides a broad description of the indicator composite building process. For more detailed descriptions of indicators and sources of information, and methods used to identify resilient conditions and/or composite indicators, see Appendix A. Appendix A contains additional information for some, but not all, of the indicators as well as for composite indicators. For some indicators, there was a need to further explain the rationale behind the desired resilient condition, provide more details regarding the data sources and modifications to the data, and/or discuss constraints in the analysis. Overall, this appendix serves to provide the reader with a closer look at certain indicators in order to present a full picture of methodologies and caveats.

It should be noted that the indicators described here apply only to the LTW project area. The Design Team did not evaluate resilience for the analysis area (which includes portions of the Tahoe and Eldorado National Forests) at this time because comparable data are not yet available for the Eldorado National Forest. However, some of the indicators were mapped in the analysis area (Appendix B) where data were available.

Landscape Values and Services and Primary Disturbances

Through an iterative process, the Interagency Design Team and science stakeholders, with input from the Stakeholder Community Committee and Science Team, selected landscape values and services that would be assessed as part of the Landscape Resilience Assessment to determine how resilient they are to major disturbances. The broad landscape values and services selected were: upland ecosystems, meadow/riparian ecosystems, aquatic ecosystems, public health and safety, cultural landscapes, and recreation (Appendix C). The primary disturbances evaluated were: fire (including smoke), flood, drought, insects and disease, climate change, erosion, air pollution (other than smoke from fire), human presence and activity, and the built environment. The resilience of the landscape values and services to the built environment will be the focus of finer-scale analysis in future phases of the LTW project.

Individual Indicators

The Design Team took the landscape values and services, and primary disturbances and evaluated which data were available to assess the current state of resilience. In total, the Design Team evaluated 21 indicators during this phase. Nineteen of the indicators had data available to evaluate resilience. Two additional indicators (treatments and vegetation types) are considered "overlays", meaning they provide information on where certain treatments have been implemented on the landscape and where a vegetation type (e.g., mixed conifer) exists, but do not in and of themselves evaluate if the landscape is resilient where those conditions exist. All indicators were assigned to one or multiple landscape values/services and primary disturbances, depending on their applicability to multiple values and disturbances.

It is generally understood that efforts to achieve ecosystem sustainability and persistence are likely to be more successful if they maintain ecosystems within the bounds of natural variation rather than targeting static equilibrium conditions from some point in the past (Wiens et al. 2012). Historic and/or contemporary reference conditions, where available, were used to help define a range of natural variation for each of the 19 indicators, which were used to develop a range of resilient conditions for each indicator. Contemporary reference conditions are areas with minimal anthropogenic impacts where natural disturbance regimes have persisted. Where reference data were not applicable (e.g., human access), the Design Team selected thresholds (e.g., ½ mile from trail, ¼ - ½ mile from trail) for a quantitative resilience assessment. From this analysis, the Design Team assigned the indicator a quantitative value for resilience from 0 to 1. These values were then assigned to a resilience class based on discrete values; 0: resilient, 0.25-0.75: less resilient, 1: least resilient.

All indicators were spatially tied to a location on the landscape using Ecological Object Based Vegetation Mapping (EcObject) which is derived from aerial-based Light Detection and Ranging (LiDAR) data (2010). These data were updated to include landscape changes since 2010 (Conway 2017). Indicators were either evaluated using EcObject or were appended to the EcObject dataset. (All maps are included in Appendix B.) The LTBMU EcObject product represents a novel forest-wide existing vegetation dataset produced by the Region 5 Remote Sensing Lab that incorporates LiDAR into several facets of the mapping process. It is created from a multi-resolution segmentation of LiDAR-derived tree approximate objects and a 1-m canopy height model, which were then aggregated by stand and tree-level ecologic relationships. The resulting segments were then populated with a collection of traditional and contemporary metrics at scales that benefit both project-level planning and large-landscape analysis. Different combinations of multi-dimensional datasets were used to estimate metrics and thus accuracies vary depending upon both the data used and workflows that were generated.

The 21 indicators may be further refined with Phase 2 of LTW (Appendix E). Also, some indicators that were originally removed during Phase 1 due to lack of data or resilience information and require additional refinement through science modelling may be put back into the list of active indicators. There are 12 total removed indicators described in Appendix D.

Indicators Assigned a Resilience Value

1. Mean Condition Class (Mean Fire Return Interval Departure Condition Class)

Mean Condition Class is based on Fire Return Interval Departure data for condition class (Safford et al. 2011). These data quantify the difference between current and pre-settlement fire frequencies, allowing managers to target areas at high risk based on where natural fire cycles have been missed. Fire interval departure gives us an idea of where uncharacteristic fuels loads and tree densities may exist on the landscape. Areas further departed may have higher fuel loadings and are less resilient to fire, and potentially to drought as well.

Resilient Condition (0): All of the landscape is in Condition Class 1.

Condition Class	Resilience Rank	Description
Condition Class 1 (0 – 33% departure)	0	Resilient
Condition Class 2 (33 – 67% departure)	0.5	Less Resilient
Condition Class 3 (> 66% departure)	1	Least Resilient

2. Fire Severity (Wildfire High Severity Patch Size)

Fire severity patch size identifies areas on the landscape that are more or less prone to large patches of high severity fire and high tree mortality if a wildfire should burn in that area. Large patches of high severity fire removes mid- and late-seral forest characteristics which degrades the resilience of these ecosystems and the value of wildlife habitat, and places such ecosystems on uncharacteristic trajectories (e.g. transitioning from a forest to a shrub ecosystem).

Fire modeling based on the fire simulator was used to evaluate high severity patch size. The Design Team assumed that anything over a six foot flame length may be a high severity fire. (See Appendix A for additional methodological information).

Resilient Condition (0): High severity patch sizes are less than or equal to 40 acres.

Patch Size (All Veg Types)	Resilience Rank	Description
≤ 40 acres	0	Resilient
> 40 acres	1	Least Resilient

3. Trees per Acre

Trees per acre (TPA) is an indicator of resilience of upland forests and in some cases meadow/riparian ecosystems to fire, insects, disease, drought and climate change. In general, as forests become more dense (e.g., more TPA), they are less resilient to various disturbances. The acceptable resilient condition for the TPA indicator came from the published literature sources for historic and contemporary reference conditions. The range of resilience does not include associated information on tree size classes or forest seral stages. This metric does not include saplings and seedlings. (See appendix A for additional methodological information).

Resilient Condition (0): The number of trees per acre is similar to the mean of historic and/or contemporary reference data for the five vegetation types for which data are available.

Vegetation Type	Number of Trees per Acre and Resilience Rank[1]		
	Resilient (0)	Less Resilient (0.5)	Least Resilient (1)
Jeffrey pine	0-60	60-130	>130
White fir – mixed conifer	0-55	55-100	>100
Red fir	0-80	80-247	>247
Subalpine	<140	N/A	≥140
Aspen[2]	<200 SDI	200-400 SDI	>400 SDI
[1] Resilient = mean of historic and/or reference condition data for trees per acre. Less Resilient = Greater than mean of historic and/or reference condition data but within upper range of trees per acre as described in the literature for that vegetation type. Least Resilient = Trees per acre exceeds that which has been documented in the literature. [2] Data for aspen is in Stand Density Index (SDI) and not Trees per acre.			

4. Meadow Refugia

Meadows that are well connected and provide future climate refugia may be more resilient to future disturbances and would potentially provide more stable habitat for terrestrial and aquatic species. Refugia is defined as areas on the landscape where the magnitude of change in climate and climate-derived measures was minimal, as measured from a baseline period of 1910–1939 and focused on temperature, precipitation, and water balance variables (Maher et al. 2017). The Design Team focused on evaluating refugia based on minimum temperature (2010-2039) and annual precipitation from modeled from the GFDL-A2 (warmer and drier climate scenario) (Maher et al. 2017). (See appendix A for additional methodological information).

Resilient Condition (0): Meadows that provide refugia for terrestrial and aquatic species.

Refugial meadows	Resilience Rank	Description
Refugia for both Minimum Temperature* and Annual Precipitation	0	Resilient
Refugia for Minimum Temperature ***or*** Annual Precipitation	0.5	Less Resilient
No refugia status	1	Least Resilient
*minimum temperature at beginning of modeling period 2010-2039.		

5. Meadow Connectivity

Meadows that are well connected and provide future climate refugia may be more resilient to future disturbances and would potentially provide more stable habitat for terrestrial and aquatic species. All meadows were evaluated for the connectivity in terms of distance, topography, water courses, and roads and trails based on Morelli et al. (2016) and Moher et al. (2017). (See appendix A for additional methodological information).

Resilient Condition (0): Meadows that are really well connected because these are more resilient to ecosystem disturbance (e.g. climate change, insects and disease, fire, etc.).

Refugial meadows with connectivity rankings	Resilience Rank	Description
Really Well Connected	0	Resilient
Well Connected	0.5	Less Resilient
Least connected	1	Least Resilient

6. Thermal Tolerance

The California Spotted Owl is sensitive to temperatures at or above 30^0C at which point body temperature elevates and body width index (piloerection) increases. At temperatures at or above 32^0C breathing rate increases. At temperatures at or above 34^0C, gular fluttering, gaping, and drooping of the wings occurs. The upper critical temperature for the California Spotted Owl is 35.2^0C, where resting metabolic rate increases exponentially (Weathers et al. 2001). Data for spotted owl thermal tolerance may be extrapolated as a threshold to other wildlife species, where there is limited data. Also, these data can inform what may happen to the owl population as well as their prey as temperature warms.

The Interagency Design Team used data for the 2025 projected median value of the total number of days between May through September for which the daily maximum temperature exceeded the threshold temperature of 30°C based on an ensemble of 10 global climate models and the RCP 4.5 emission scenario. (See Appendix A for additional methodological information).

Resilient Condition (0): In 2025, there will be a total of five or fewer days between May through September with temperatures that exceed 30°C.

Number of days temperature exceeds 30^0C in 2025	**Resilience Rank**	**Description**
0-5	0	Resilient
6-13	0.25	Less Resilient
14-19	0.5	Less Resilient
20-26	0.75	Less Resilient
27-42	1	Least Resilient
Note that 0.75 exists within the broader analysis area in 2025 but not in the project area; 1 also exists in 2025 just outside (and down in elevation from) the analysis area. The dataset for the state of California goes to 146.5 days.		

7. Climatic Water Deficit

Climatic Water Deficit (CWD) is a measure of plant stress. It is calculated as the difference between actual and potential evapotranspiration, which is limited by soil moisture availability. Multiple studies have demonstrated the sensitivity of ecosystems to climatic water deficit, which is a measure of water stress. Ecosystems with lower CWD are more resilient to ecosystem disturbance (e.g. climate change, insects and disease, fire, etc.). Recent work has shown a strong connection between resilience of drought induced beetle mortality and climatic water deficit (e.g., Restaino et al. 2017).

The Design Team used climatic water deficit for 2015, which was a significant drought year, from the California Basin Characterization Model (Flint, Lorraine E., Alan L. Flint, org: USGS). This dataset provides historical and projected climate and hydrologic surfaces for the state of California and all the streams that flow into it. (See Appendix A for additional methodological information).

Resilient Condition (0): CWD less than 600 mm because it is more resilient to ecosystem disturbances.

Probability of tree mortality	**CWD (mm)**	**Resilience Rank**	**Description**
~15%	<600	0	Resilient
15-65%	600-800	0.5	Less Resilient
>65%	>800	1	Least Resilient

8. Snowpack

Snowpack changes are a well-documented, key indicator of resilience to climate change. Snowpack is important to both ecosystem processes and various human resources such as drinking water. The Design Team used the California Basin Characterization Model (Flint, Lorraine E., Alan L. Flint, org: USGS) to identify where there was snow on April 1, 2015. Typically, April 1st marks the start of significant snowmelt, which is an important measure for recharge of lakes, streams, and groundwater dependent ecosystems. 2015 was a significant drought year, so the areas with snow on April 1 represent the potentially most resilient locations. All areas with any snow on that date were considered resilient, while all areas without snow on that date were considered least resilient. (See appendix A for additional methodological information).

Resilient Condition (0): Snowpack is present on April 1st.

Snowpack April 1st 2015	Resilience Rank	Description
Yes	0	Resilient
No	1	Least Resilient

9. Fire Risk Index

The Modified Fire Risk Index measures the relative risk of human populations and infrastructure (values at risk) to the threat of wildland fire. The fire risk index combines an estimate of the probability of an area being threatened by wildfire (fire threat) and an estimate of the values that would be damaged by a wildfire at the predicted severity (fire effects). The Modified Fire Risk Index measures the relative resilience of the public health and safety values to wildland fire. The Fire Risk Index was developed through the West Wide Wildfire Risk Assessment Project in 2014. It combines inputs including the locations of human populations and infrastructure, probability of ignitions, probable fire behavior, historic weather patterns, and local suppression capability. Fire Risk Index was weighted by the canopy cover slices from EcObject and LANDFIRE vegetation condition class for the Modified Fire Risk Index.

Modified Fire Risk Index values are relative to other areas in the landscape, therefore the acceptable resilient conditions were defined based on quantiles, and then compared to established Wildland Urban Interface boundaries. (See Appendix A for additional methodological information).

Resilient Condition (0): The landscape has the relatively lowest Modified Fire Risk Index values in areas near human habitation (i.e., Wildland Urban Interface threat and defense zones).

Modified Fire Risk Index Percentile	Resilience Rank	Description
0-50	0	Resilient
50-80	0.5	Less Resilient
80-100	1	Least Resilient

10. Roads and Trails Linked to Water Channels

This indicator is intended to give a general indication of resilience to water quality impacts from flooding. For the purposes of this Assessment, a crossing with a culvert is considered more resilient than a crossing without a culvert. Channel crossings on roads and trails that have functioning culverts can reduce the potential for sediment loading where the intersection occurs. Due to data limitations, this indicator does not consider whether or not the culvert is adequately sized or functioning. However, all crossings without a culvert were ranked as 1, least resilient.

Also, this indicator does not consider that crossings may be rock armored or have other appropriate best management practices (BMPs) in place that would make it more resilient. In future phases when more data may be available, this desired resilient condition may be revised to state that these intersections have sufficient BMPs (and not necessarily a culvert) to reduce sedimentation potential. (See appendix A for a figure representing spatial data used to evaluate resilience).

Resilient Condition (0): Where trails and roads intersect water crossings, these intersections have a culvert that reduces the potential for sediment loading.

Channel Crossing with Culvert	Resilience Rank	Description
Yes	0	Resilient
No	1	Least Resilient

11. Human Access

This indicator is intended to identify areas of the landscape that are most impacted by noise and other impacts associated with human presence and use. These areas are more vulnerable to the introduction of invasive species associated with human activities and are less likely to be used by wildlife species that are sensitive to human presence. Human access is generally concentrated on roads and trails. Therefore, it is assumed that areas closest to roads and trails are less resilient in terms of human presence than areas further from roads and trails. The further from concentrated human use, the more resilient the landscape condition. This is where the most sensitive species to humans have suitable habitat, as large ranging, specialized species (e.g., spotted owl, northern goshawk and American marten) can be especially sensitive to noise associated with human presence.

The Design Team classified trail and road buffers as described in the table below. This indicator is based on data provided in the TRPA-managed spatial information for impervious coverage.

Resilient Condition (0): Land that overlaps with spotted owl, goshawk, and marten habitat is > ½ mile from roads or trails.

Distance from Road or Trail	Resilience Rank	Description
> ½ mile from road or trail	0	Resilient
¼ mile to ½ mile	0.5	Less Resilient
< ¼ mile of a road or trail	1	Least Resilient

12. Water Quality

This indicator provides an indication of which portions of the landscape are susceptible to increased erosion and sediment loading to water bodies from disturbance. Such disturbances primarily include human activity, fire, and flooding. The water quality indicator is based upon the Bailey's Land Capability Classification System (Bailey 1974). The system combines hazard ratings based upon soil type, slope, infiltration rates, and a hazard rating based upon geomorphic setting to assign a land capability score, ranked 1-7, with the lowest ranking broken into three categories (1a, 1b, and 1c). These rankings represent the relative tolerance to human disturbance. The Design Team assigned a value to each ranking based upon the relative hazard (high, moderate, or low hazard lands, and the value of allowable disturbance for each) as shown below.

For this indicator, resilience is ranked according to sensitivity to human disturbance, specifically creation of impervious coverage, because these areas create long lasting impacts on the landscape. (See appendix A for additional methodological information).

Resilient Condition (0): Soils outside the Wildland Urban Interface in the LTW project area are ranked as low hazard lands (5, 6, and 7).

Land Capability Classification	Hazard	Resilience Rank	Description
7, 6	Low	0	Resilient
5	Low	0.2	Less Resilient
4	Moderate	0.4	Less Resilient
3	Moderate	0.6	Less Resilient
2, 1a	High	0.8	Less Resilient
1b, 1c	High	1	Least Resilient

13. Aquatic Organism Passage

This indicator measures the presence of man-made barriers to fish passage in streams in the LTW project area. Streams with no man-made barriers are assumed to have a higher amount of aquatic organism connectivity. These streams are considered more resilient because aquatic organisms are able to move throughout the stream to find refugia in times of drought or climate change.

The Design Team examined which barriers are prohibitive to sculpin movement, the lowest barrier threshold for native fish. Sculpin were selected as the threshold because they are native to these creeks and are relatively weak swimmers (limited jumping ability to get over barriers). Therefore, if sculpin have made it up the creek then one can assume that most other fish that comprise the food web are present as well. Barriers impede movement and connectivity in the stream, thus only streams with no barriers to sculpin passage were considered resilient. (See Appendix A for a data caveat).

Resilient Condition (0): All streams in the LTW project area can pass sculpin.

Sculpin Passage	Resilience Rank	Description
No man-made barrier or sculpin can pass barrier	0	Resilient
Barrier that sculpin cannot pass	1	Least Resilient
Data for this indicator were based on the 2010 and 2011 Aquatic Organism Passage Assessment (USDA 2010 and 2011).		

14. Floodplain Condition

The extent of floodplain encroachment addresses the resilience of meadow/riparian and aquatic ecosystems to flood, drought, climate change, and erosion. In addition, it addresses the resilience of public health & safety and recreation to flooding. While the majority of the landscape is not assessed with this metric, it is key to understanding the health and resilience of meadow/riparian ecosystems. The encroachment of impervious coverage impedes the ability of floodplains to perform their natural processes. Processes include flood- and base-flow attenuation as well as filtration and sediment capture for water quality benefits. Structures built within floodplains are more likely to be damaged by flooding, and are therefore less resilient than buildings above the floodplain.

This indicator is currently assessed as the areas within the FEMA 100 year floodplain, or TRPA defined Stream Environment Zone (SEZ, Bailey class 1b) that contain impervious surfaces, including structures, roads, and trails.

Resilient Condition (0): No impervious surfaces within a floodplain/SEZ.

Floodplain Condition	**Resilience Rank**	**Description**
Does not contain impervious surfaces	0	Resilient
Does contain impervious surfaces	1	Least Resilient

15. Bark Beetle Predators

The resilience of a forest system is influenced by factors other than forest structure and disturbance dynamics. Many species and groups of species play important functional roles and, under changing environmental conditions, species with previously minimal functional responsibilities may take on increasingly important functional roles. The persistence of these functional groups is essential for ecosystem resilience. One functional group that plays a very important role in ecosystem resilience in the Lake Tahoe Basin is the cavity nesting bird guild that acts as primary predators on bark beetles and other potentially disruptive forest insects, including non-native insect pests.

Cavity nesting birds are important predators on bark beetles, which have contributed to recent conifer die-off events in the Lake Tahoe Basin and Sierra Nevada. These birds act as a biological control agent to moderate and reduce the effects of insect outbreaks and promote forest resilience to drought, insects, and climate change (Fayt et al., 2005). The suite of forest cavity nesters may moderate the onset, distribution, duration, or intensity of outbreaks by delaying the initiation of an outbreak and/or increasing the trajectory of decline after the peak of the outbreak (Martin et al. 2006). This moderation could result in a substantial decline in total tree mortality during a drought-induced beetle outbreak.

The Design Team ranked the resilience for this indicator based data developed by White and Manley (2013). Fourteen probability of occurrence rasters were averaged and Jenks natural breaks were generated to assign a resilience rank. (See Appendix A for additional methodological information).

Resilient Condition (0): Habitat with the highest probability of occurrence for all cavity nesting bird species.

Bark Beetle Predator Probability of Occurrence	**Resilience Rank**	**Description**
0.383671916 - 0.49116981	0	Resilient
0.354354308 - 0.383671916	0.25	Less Resilient
0.317707299 - 0.354354308	0.5	Less Resilient
0.270066186 - 0.317707299	0.75	Less Resilient
0.17967023 - 0.270066186	1	Least Resilient

16. Native Fish Diversity

The presence and diversity of native fish species in a stream is an indicator of habitat quality, connectivity, and complexity – essentially, more native species from multiple trophic levels indicates a more resilient stream. Streams with a greater ratio of native species than non-native species are more resilient to disturbances. For this indicator only streams that have more native species than non-native species are considered resilient (this indicator is focused on species diversity and does not incorporate abundance into the resilience rank). (See appendix A for additional methodological information).

Resilient Condition (0): Streams have more native than non-native species.

Native Fish Diversity	Resilience Rank	Description
More native than non-native species	0	Resilient
Fewer native than non-native species	1	Least Resilient
Data for this indicator come from the LTBMU Basin-wide native non-game fish assessment 2007-2014 comprehensive report (USDA 2016).		

Indicators with Proportional Resilience Values

Three indicators (vertical heterogeneity, horizontal heterogeneity, and seral stage) do not have location-specific resilience assessments. For all three indicators, there are data to suggest how much heterogeneity and how many seral stages there should be on the landscape, based on reference conditions, and how much there currently is, but the data do not suggest *where* specifically each of these states or stages should be on the landscape. Therefore, the resilient condition for each of these indicators is to have proportions represented on the overall landscape similar to reference conditions. Decisions on locations to improve heterogeneity or develop certain seral stages on the landscape will be determined through the LTW collaborative and science-based process during the development of the Landscape Restoration Strategy.

The resilience scale for proportional resilience values is the same as for individual indicators. This scaling was maintained to provide for scaling up and combining multiple indicators to evaluate resilience. Items that are outside of acceptable resilient conditions and are under-represented across the landscape were assigned a resilience rank of 0.5. These areas have a higher risk of being lost from the landscape. Items that are outside of acceptable resilient conditions because they are over-represented were assigned a resilience rank of 1. All other conditions with data were given a resilience rank of 0.

17. Seral Stage

Percent of seral stage across the landscape is an indicator of resilience of upland forest and in some cases meadow/riparian ecosystem to fire, insects, disease, drought and climate change. Seral stage was developed based on tree size classes and canopy cover, both of which can affect competition, fire behavior, susceptibility to pest infestations, etc. Additionally, this indicator provides information related to heterogeneity, which ties to the resilience of wildlife habitat.

For this indicator two data sources were used: desired conditions from the LTBMU Forest Plan (USDA 2016) and the Yuba River Historic Range of Variation analysis, which was summarized by Becky Estes in the draft South Fork American River Desired Conditions. Due to differences in seral classifications, cut-offs incorporated the larger end of the upper and lower range to provide a more liberal range. (See appendix A for additional methodological information).

Resilient Condition (0): All seral stages on the landscape are represented in similar proportions to reference conditions.

Seral Stage[1]	Resilient Condition		
	Yellow Pine	**Mixed Conifer**	**Red fir**
EDO	5-15%	5-20%	3–20%
EDC	0%	0%	0%
MDO	8-25%	1-15%	0-15%
MDC	0-10%	0-15%	12-30%
LDO	29–50%	6-50%	2-15%
LDC	5–31%	7-79%	25–70%

[1] Seral stage refers to overstory tree DBH (inches) and overstory tree canopy from above. Early development (ED): ≥5" & <25%; Mid development open (MDO): 5-19.9" & <40%; Mid development moderate (MDO): 5-19.9" & 40-70%; Mid development closed (MDC): 5-19.9" & >70%; Late development open (LDO): >20" & <40%; Late development moderate (LDM): >20" & 40-70%; Late development closed (LDC): >20" & >70%.

18. Vertical Heterogeneity

Spatial patterns are important resilience indicators because they influence disturbance behavior, regeneration, snow retention, and habitat quality. Unfortunately, there is limited reference information identifying resilient conditions. Vertical heterogeneity was evaluated using Illilouette Basin reference sites.

The resilient conditions for each vertical heterogeneity class focus on the ranks and use the percentile range as a guide. (See appendix A for additional methodological information).

Resilient Condition (0): The landscape is heterogeneous and all vertical heterogeneity classes are represented in similar proportions to reference conditions.

Vertical Heterogeneity Class	Strata Distribution Class	Resilient Condition		
		Rank	**Lower % Range**	**Upper % Range**
Single old	Top Loaded	1	49.22	73.83
Homogeneous mid	Mid Loaded	2	13.52	20.28
Codominant - attached	Bimodal – Codominance	3	11.39	17.08
Tri-dominant – 3 equal classes	Continuous	4	3.32	4.97
Single young*	Bottom Loaded	5	2.05	3.07
Codominant - detached	Bimodal – Subdominance	6	0.51	0.76

* Early seral stands.
Numbers are the rank with 1 being the greatest proportion of that individual class and 6 being the lowest proportion of the class.

19. Horizontal Heterogeneity

Similar to vertical heterogeneity, horizontal heterogeneity spatial patterns are important resilience indicators because they influence disturbance behavior, regeneration, snow retention, and habitat quality. Heterogeneity across the landscape will increase landscape resilience. Two data sources were used to evaluate horizontal heterogeneity: 1) Illilouette Basin reference sites and 2) data from (Lydersen et al. 2013). These two sources allowed the Design Team to bracket the range of resilient conditions presented below. The resilient conditions for horizontal heterogeneity was further evaluated by landscape management unit (ridge, canyon, NE and SW slopes). (See Appendix A for additional methodological information).

Resilient Condition (0): The landscape is heterogeneous and all vertical heterogeneity classes are represented in similar proportions to reference conditions.

Horizontal Heterogeneity Class	Lower % Range	Upper % Range
Individuals/Sparse[1]	1	7
Open (Gaps)	20	27
Stand initiation[2]	17	
Scattered clumps (2-4 trees, low cover)	13	36
Clump (medium 5-9 trees)	11	15
Dense clump (large, >10 trees)[3]	0.5	66
All clumps[4]	48	

[1] Note sparse class was lumped into individuals, however based on how data was processed this could have been lumped into scattered clumps as well, lowering the range of scattered clumps to 7%.
[2] Stand initiation was likely considered a "gap" under Lyderson, however this class in EcObject indicates that the gap could transfer to forested stand while other gaps may not and therefore this was kept separate. This class would be considered early seral.
[3] Note this is a very large range. 0.5 is from Illilouette and 66% is from Lyderson.
[4] This was calculated by summarizing all clumps from the Illilouette data.

Visual Overlay Indicators

20. Treatment Type

Although mean condition class (indicator #1 above) describes the difference between current and pre-settlement fire frequencies, management actions such as small prescribed fires may not have been captured in the Fire Return Interval Departure (Indicator 1). Additionally, although fire is a unique tool that thinning alone cannot replicate completely, thinning activities are important for increased resilience. The land managers have conducted thinning operations that are not captured by the Fire Return Interval Departure dataset. These treatments are important to visually illustrate on a map but do not tell us if these treated areas are now resilient (or conversely, that untreated areas are not resilient). Therefore, this indicator is intended to be used as a visual overlay on a map (Appendix B).

Data were incorporated for all treatments conducted within the last 10 years. The Design Team assumed that treatments older than 10 years may have been implemented differently than current treatments (data quality may be lower for older data) and may not be as resilient due to the longevity of different treatments – especially in relation to fire return interval. Data are the best available data from state and federal agencies. (See Appendix A for additional methodological information).

21. Vegetation Type

A diverse representation of vegetation types across the landscape will increase resilience to fire, insects, disease and drought because different vegetation communities respond differently to type and magnitude of disturbance. More diverse vegetation types also translate into more habitat types for wildlife diversity.

Two spatial datasets (Landfire and VTM) suggestive of the historical range of variability were used to bracket the percentage of each vegetation type. These data can be used to compare current proportions of each vegetation type to historic conditions, however these data cannot be used to identify which location of each vegetation type is within or outside of resilient condition. Therefore this indicator is not used to evaluate spatial resilience but may be used to represent overall proportional resilience. This indicator is spatially presented in terms of which vegetation types are found in the LTW project area and where each type is found (Appendix B). (See Appendix A for additional methodological information).

Composite Indicators

In addition to individual, stand-alone assessments of each indicator, indicators were also combined into composites by averaging three to 18 indicators, depending on how many individual indicators comprised the composite indicator that was to be developed. The intent of the composite indicators was to identify potential hotspots where multiple indicators identified similar resilience. Composites were determined based on the value-disturbance-indicator table (Appendix C). This table compared landscape values and services (e.g. aspen forests) to primary disturbance type (e.g. fire, flood). Each individual indicator was placed in a cell of the table where that indicator was considered a primary indicator (e.g. fire severity was identified as a primary indicator for forests and fire). Note that each cell could have multiple indicators and an indicator could be identified in multiple cells if it was considered a primary indicator for that disturbance and landscape type or value.

Indicators were then averaged horizontally across disturbance type and vertically across values and services (see Appendix C) to create the composite indicators. Each indicator was only counted once in each composite index even if it was found in multiple cells across that disturbance or value. For example, fire severity occurred in forests, meadows and marshes, aspen, and riparian cells for fire disturbance but was only counted once in the average for the composite indicator of resilience to fire. In order to make sure indicators weren't duplicating information (i.e., they weren't correlated) within a composite, each indicator's resilience was evaluated for correlation (Appendix A).

Below is a list of the composite indicators developed and the individual indicators that comprise those composites; see Appendix C for a display of these indicators by disturbance type and landscape value:

- Resilience to **fire**: mean condition class, fire severity, trees per acre, fire risk index, roads and trails linked to water channels, human access, water quality, seral stage (proportional), vertical heterogeneity (proportional), and horizontal heterogeneity (proportional).
- Resilience to **flood**: roads and trails linked to water channels, water quality, and floodplain condition.
- Resilience to **drought:** trees per acre, meadow refugia, meadow connectivity, climatic water deficit, snowpack, aquatic organism passage, floodplain condition, bark beetle predators, native fish diversity, and seral stage (proportional).
- Resilience to **insects and disease**: trees per acre, climatic water deficit, bark beetle predators, and seral stage (proportional).

- Resilience to **climate change**: fire severity, trees per acre, meadow refugia, meadow connectivity, thermal tolerance, climatic water deficit, snowpack, human access, floodplain condition, bark beetle predators, native fish diversity, and seral stage (proportional).
- Resilience to **erosion**: roads and trails linked to water channels, human access, water quality, and floodplain condition.
- Resilience to **human presence and activity**: roads and trails linked to water channels, human access, and floodplain condition.
- Resilience of **ecosystems**: mean condition class, fire severity, trees per acre, meadow refugia, meadow connectivity, thermal tolerance, climatic water deficit, snowpack, roads and trails linked to water channels, human access, water quality, aquatic organism passage, floodplain condition, bark beetle predators, native fish diversity, seral stage (proportional), vertical heterogeneity (proportional), and horizontal Heterogeneity (proportional).
- Resilience of **public health and safety**: trees per acre, snowpack, fire risk index, roads and trails linked to water channels, water quality, and floodplain condition.
- Resilience of **recreation**: fire severity, trees per acre, snowpack, fire risk index, roads and trails linked to water channels, and human access.

After averaging, each composite indictor had a continuous resilience rank between 0 and 1, and displayed spatially similar to the individual indicators (Appendix B). These values were then assigned to a resilience class since the data for composite indicators was continuous (versus discrete) Therefore additional classes were developed in order to evaluate the landscape. The composite resilience classes are: 0-0.2: high resilience, 0.21-0.4: moderate resilience, 0.41-0.6: less resilience, 0.61-0.8: low resilience, and 0.81-1: least resilience. Composite indicators were further evaluated identifying the resilience trend, which assessed if more of the landscape was greater than 0.41 (more of the landscape in non-resilient condition) or less than 0.6 (more of the landscape in a resilient condition.

Results and Discussion

The results of the Landscape Resilience Assessment are characterized in qualitative descriptors intended to help make broad comparisons as to which portions of the landscape for an individual or composite indicator range of resilience. There are cases where an indicator(s) would indicate a resilient condition while another indicator(s) would indicate a less or least resilient condition at the same spatial location. Each indicator varied in quality of data, and confidence in application of the indicator to resilience. Therefore the following results should be interpreted with an understanding of the data limitations. The quality and confidence of each indicator is not presented in this document, therefore the reader should take time to understand the both the general and technical methodology presented in the methods section above and Appendix A. Future versions of the Assessment may want to consider developing a matrix to evaluate the quality and confidence in the individual resilience indicators.

Indicators

Indicators Assigned a Resilience Value

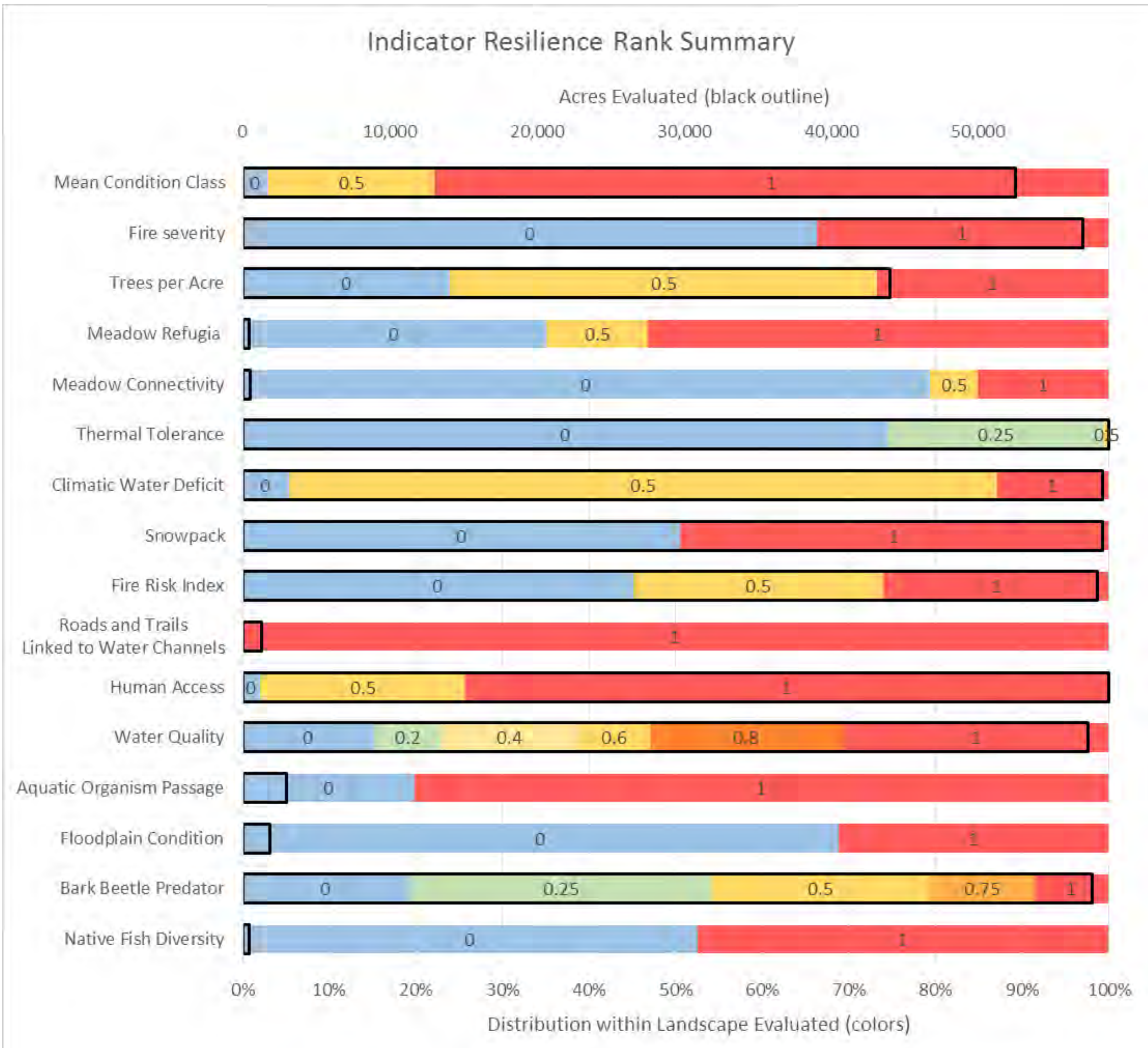

Figure 3. For each indicator, the percent area of each resilience rank is displayed with colored bars – bottom x axis. A value of 1 indicates least resilient and 0 represents resilient. Numbers between 0 and 1 indicate varying levels of resilience. The proportion of the Lake Tahoe West landscape assessed for each indicator is displayed in the black-outlined bars – top x axis. Areas outside the black lines are portions of the landscape that either 1) data did not exist for or 2) were not representative for the indicator.

1. Mean Condition Class (Mean Fire Return Interval Departure Condition Class)

The data indicates that three percent of the assessed landscape is in a resilient condition, 19% is less resilient, and 78% of the landscape is least resilient (Figure 3). These results indicate overall high departure from pre-settlement fire regimes. Some areas, such as riparian areas, meadows and grasslands, were not assigned a condition class due to uncertainty with historic fire regimes. Spatially in the LTW project area, areas closer to Lake Tahoe are least resilient and areas further from Lake Tahoe in canyons and at higher elevations are ranked as less resilient (Appendix B, Indicator 1). While the majority of the LTW project area is substantially departed, some areas of high elevation red fir and limited patches of yellow pine stands are less departed. The red fir patches are most prevalent on the south side of the landscape near and within Desolation Wilderness, and on the west side near Granite Chief Wilderness. These high elevation areas would have historically burned with less frequency. The lower elevation yellow pine areas are typically near areas with riparian vegetation.

2. Fire Severity (Wildfire High Severity Patch Size)

Sixty-six percent of the landscape is resilient while 34% of the landscape has some probability of large patches (greater than 40 acres) of high severity fire and is identified as least resilient (Figure 3). The resilient areas may still experience high severity fire, however it would not be in a continuous patch larger than 40 acres. Spatially, in the LTW project area, the majority of the area that is least-resilient occurs in canyons/drainages (Appendix B, Indicator 2). Most predicted high severity patches are within the Wildland Urban Interface, with limited patches in the general forest. Large patches tend to accumulate centered around drainage bottoms. The north side of the landscape contains the largest continuous predicted high severity patches within the project area. Additional large high severity patches are predicted in the analysis area near the Olympic Valley and west of Granite Chief Wilderness.

3. Trees per Acre

Twenty-four percent of the forested landscape is considered resilient (Figure 3), meaning these areas have the number of trees per acre that are consistent with historic and/or contemporary reference conditions. Forty-nine percent of the project area assessed is considered less resilient and 27% of the landscape is considered least resilient (Figure 3). Resilient areas are located at higher elevations and in the wilderness, while least resilient areas are typically located in canyons and are intermixed with less resilient areas (Appendix B, Indicator 3).

4. Meadow Refugia

Based on the GFDL-A2 climate scenario, using annual precipitation and minimum temperature at the beginning of the modeling period (2010-2039) (Maher et al. 2017) there were 59 meadows that are identified as least resilient, six meadows identified as less resilient, and 29 meadows that are identified as resilient (Appendix B, Indicator 4). This represents 53%, 12%, and 35%, respectively, of the assessed meadow area (Figure 3). Resilient meadows are located in the southern portion of the project area, near the shore of Lake Tahoe. Less resilient meadows are found in Blackwood Canyon. The least resilient meadows are located at higher elevations and in the northern portion of the project area (Appendix B, Indicator 4).

5. Meadow Connectivity

Sixty-two meadows are very well connected (resilient), five are well connected (less resilient), and 27 are “stable” or not connected (least resilient) (Appendix B, Indicator 5). This represents 79%, 6%, and 15%, respectively, of the assessed meadow area (Figure 3). Meadows that are resilient and less resilient are generally connected. Meadows in the northern portion of the project area are the least resilient (Appendix B, Indicator 5).

6. Thermal Tolerance

Seventy-four percent of the landscape is resilient and 26% is less resilient, while none of the project area is least resilient (Figure 3). Lower resilience areas were found within the LTW analysis area, but not within the project area. This result indicates that the LTW project area could act as a future refugia for wildlife species with low thermal tolerances if they're able to relocate into the west shore. Resilient areas are found at higher elevations and within the wilderness (Appendix B, Indicator 6).

7. Climatic Water Deficit

In 2015, CWD ranged from 244 to 1293 mm (Appendix A). Five percent of the landscape is resilient, 82% is less resilient, and 13% is least resilient (Figure 3). This indicates moderate levels of water stress and susceptibility to drought-induced beetle mortality. The most resilient areas on the landscape are found in the LTW analysis area, but not the project area. Least resilient areas are found in canyons and along the shore of Lake Tahoe (Appendix B, Indicator 7).

8. Snowpack

In 2015, April 1st snow water equivalent ranged from 0 to 227 inches (Appendix A). Fifty percent of the landscape is resilient and 50% is identified as least resilient (Figure 3). Resilient areas are found at higher elevations, while the least-resilient areas are closer to the shore of Lake Tahoe (Appendix B, Indicator 8). Ridges and show the most resilience (71% by area). Canyons are nearly equally resilient (48%) and least resilient (51%). Additionally, slopes under 30% -- both NE and SW facing – have a greater amount of least resilience, while slopes over 30% show slightly more resilience.

9. Fire Risk Index

Forty-five percent of the landscape is resilient, 29% is less resilient, and 26% is identified as least resilient. Because this indicator is relative to the Lake Tahoe West landscape, it indicates areas of greatest concern for wildland fire management and fuel reduction (Figure 3). The least resilient areas are typically in close proximity to neighborhoods and infrastructure because they are weighted to have higher fire risk (Appendix B, Indicator 9). There are also extended areas of higher risk within the Wildland Urban Interface threat zone and general forest near Dollar Point and southwest of Tahoma.

10. Roads and Trails Linked to Water Channels

Two percent of the landscape was assigned a resilience rank for this indicator, representing patches where roads and trails intersect with water channels. These crossings are identified as least resilient because they do not have a culvert. Locations with culverts were not evaluated, since there is not data available on the size and condition of culverts. The Burton Creek, Ward Creek, and Blackwood Creek watersheds show the greatest clustering of areas where roads and trails cross streams without a culvert (Appendix B, Indicator 10).

11. Human Access

The majority of the landscape in the LTW project area is considered least resilient (74%) because it is within ¼ mile of a road or trail. Twenty-four percent of the LTW project area is between ¼ and ½ mile of a road or trail, and assigned a ranking of less resilient. Only 2% of the landscape is considered resilient with no roads or trails within ½ mile (Figure 3). Spatially, nearly the entire north side of the project area is proximate to human access, and there are only limited areas near and within the Desolation Wilderness that are over ½ a mile from human development (Appendix B, Indicator 11).

12. Water Quality

Fifteen percent of the landscape is most resistant to erosion and considered resilient. Thirty-one percent of the landscape is highly susceptible to erosion and water quality impacts and considered least resilient. The remaining 54% of the landscape is less resilient (Figure 3). While this resilience condition is not something that can be changed through management, it is an important consideration when designing a management strategy. For example, there will be implications for the locations of roads or the ability to do mechanical fuels treatment. High elevation areas in general have the highest hazard lands as they have the steepest slopes, especially on south facing aspects. In low elevations, high hazard lands are mostly limited to SEZs and meadows (Appendix B, Indicator 12).

13. Aquatic Organism Passage

Five percent of the landscape was assigned a resilience rank for this indicator, representing EcObject patches intersecting streams. The majority of the aquatic landscape (80%) is inaccessible to sculpin due to man-made barriers and 20% is not restricted by man-made barriers to fish passage and is considered more resilient (Figure 3). Madden creek and Cascade creek were the only creeks identified as resilient (Appendix B, Indicator 13).

14. Floodplain Condition

Three percent of the landscape was assigned a resilience rank for this indicator, representing patches within SEZs or FEMA 100-year flood plains. Thirty-one percent of this area assessed is least resilient due to the presence of impervious surfaces, while 69% of these areas are considered more resilient because they do not contain impervious surfaces (Figure 3). Areas of resilient and least resilient floodplain condition occur on the same channels (Appendix B, Indicator 14). Floodplains near Blackwood Creek, Meeks Meadow, and near the developed areas of Tahoe City have the highest proportions of impermeable coverage.

15. Bark Beetle Predators

Nineteen percent of the landscape is resilient, representing the most suitable habitat areas for bark beetle predators, 9% is least resilient, representing the least suitable habitat within the project area. Seventy-two percent is less resilient, with varying levels of habitat suitability (Figure 3). High elevation areas near Granite Chief and Desolation Wilderness, and the developed areas of Tahoe City provide the least resilient habitat for Bark Beetle Predators. Valleys provide the most resilient habitat (Appendix B, Indicator 15).

16. Native Fish Diversity

Only one percent of the landscape was assigned a resilience rank for this indicator, representing EcObject patches intersecting streams. Fifty three percent of the assessed area is resilient due to streams having more native fish species than non-native species. The remaining 47% is least resilient due to the presence of more non-native fish species (Figure 3). Ward Creek, Quail Creek, General Creek, Meeks Creek, and Cascade Creek were identified as being resilient (Appendix B, Indicator 16).

Indicators with Proportional Resilience Values

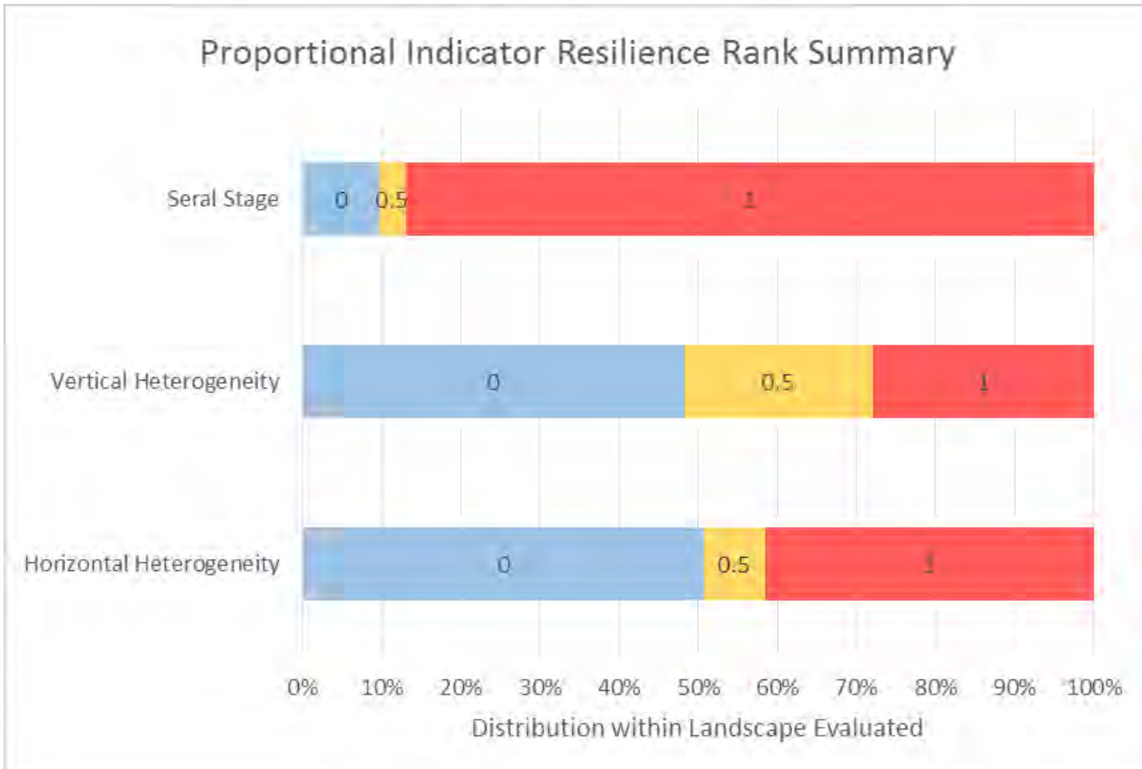

Figure 4. For each proportional indicator, the percent area of each resilience rank is displayed with colored bars. A value of 1 indicates a category that is over-represented on the landscape, 0.5 signifies under-representation, and 0 signifies a class that is appropriately represented.

17. Seral Stage

Across all vegetation types, early development stands are located primarily in higher elevations, while late development stands are scattered throughout the landscape. Mid-development open and closed are over-represented while late development open is under-represented in all forested types evaluated (yellow pine, mixed conifer, and red fir). In addition, late development closed is under-represented in mixed conifer and red fir forest types. Early development is within desired conditions for yellow pine and mixed conifer, but over-represented for red fir. The majority of the landscape contains over represented seral stages and is therefore least resilient (87%); 3% of the landscape is less resilient, and 10% of the landscape is resilient (e.g. appropriately represented) (Figure 4 and Appendix B, Indicator 17).

The below table represents the percentage of forest vegetation type resilient condition by seral stage and compared with current LTW project area conditions. Red text indicates over-representation, orange indicates an under-representation.

Seral Stage[1]	Yellow Pine		Mixed Conifer		Red Fir	
	RC²	LTW³	RC²	LTW³	RC²	LTW³
EDO	5-15	8%	5-20	11%	3–20	25%
EDC	0	0%	0	0%	0	1%
MDO	8-25	29%	1-15	31%	0-15	36%
MDC	0-10	56%	0-15	54%	12-30	34%
LDO	29–50	1%	6-50	1%	2-15	1%
LDC	5–31	6%	7-79	3%	25–70	4%

[1] Seral stage refers to overstory tree DBH (inches) and overstory tree canopy from above. Early development (ED): ≥5" & <25%; Mid development open (MDO): 5-19.9" & <40%; Mid development moderate (MDO): 5-19.9" & 40-70%; Mid development closed (MDC): 5-19.9" & >70%; Late development open (LDO): >20" & <40%; Late development moderate (LDM): >20% & 40-70%; Late development closed (LDC): >20" & >70%.
[2]RC = Resilient Condition.
[3]LTW = Condition in the Lake Tahoe West project area.

18. Vertical Heterogeneity

Twenty-eight percent of the landscape is least-resilient because it is over-represented (bottom loaded), while 24% of the landscape is less-resilient because it is under-represented (top loaded). The majority of the landscape (48%) is appropriately represented and is considered resilient (Figure 4 and Appendix B, Indicator 18). The table below represents the percentage of desired conditions by vertical heterogeneity for forested vegetation types and comparison with current LTW project area conditions. Due to the limited available data, resilient conditions for each strata distribution class focus on the ranks and use the percentile range as a guide.

Vertical Heterogeneity Class	Strata Distribution Class*	DC Rank	LTW Rank	Lower % Range	Upper % Range	LTW % of forested landscape
Single old	Top Loaded	1	2	49.22	73.83	24%
Homogenous mid	Mid Loaded	2	3	13.52	20.28	22%
Codominant – attached	Bimodal – Codominance	3	5	11.39	17.08	6%
Tri-dominant – 3 equal classes	Continuous	4	4	3.32	4.97	17%
Single young	Bottom Loaded	5	1	2.05	3.07	28%
Codominant – detached	Bimodal – Subdominance	6	6	0.51	0.76	3%

* Description was developed to help explain the Strata Distribution Class from EcObject, without needing the product guide information. Additional information can be found in Appendix A.

19. Horizontal Heterogeneity

Forty-two percent of the forested landscape is in an over-represented class (least resilient), 8% of the landscape is in an under-represented class (less resilient), and 51% is appropriately represented and is considered resilient (Figure 4 and Appendix B, Indicator 19). Across the landscape there is an over-representation of clumps across all land management units and an under-representation of open (Below table and Appendix A). Scattered clumps are over-represented on ridges, while dense clumps are over-represented in Canyons and on NE slopes.

Horizontal heterogeneity desired condition percentage of the landscape within each spatial variation class and comparison with current LTW conditions. Red text indicates over-representation, orange indicates an under-representation.

Spatial Variation Class (terminology used in Lydersen)	Lower % Range	Upper % Range	LTW % of forested landscape
Individuals/Sparse[1]	1	7	1%
Open (Gaps)	20	27	8%
Stand initiation[2]	17		18%
Scattered clumps (2-4 trees, low cover)	13	36	34%
Clump (medium 5-9 trees)	11	15	28%
Dense clump (large, >10 trees)[3]	0.5	66	6%
All clumps[4]	48		68%

[1] Note sparse class was lumped into individuals, however based on how data was processed this could have been lumped into scattered clumps as well, lowering the range of scattered clumps to 7%.
[2] Stand initiation was likely considered a "gap" under Lyderson, however this class in EcObject indicates that the gap could transfer to forested stand while other gaps may not and therefore this was kept separate. This class would be considered early seral.
[3] Note this is a very large range. 0.5 is from Illilouette and 66% is from Lyderson.
[4] This was calculated by summarizing all clumps from the Illilouette data.

Visual Overlay Indicators

20. Treatment Type

Eighty-seven percent of the forested landscape has not had any fuels treatments in the last ten years, 12.7% has had thinning, and 0.3% has had prescribed understory burning (Appendix B, Indicator 20).

21. Vegetation Type

Currently there is more mixed conifer on the landscape than what would have been represented on the landscape under the natural range of variation (Appendix A and Appendix B, Indicator 21).

Composite Indicators

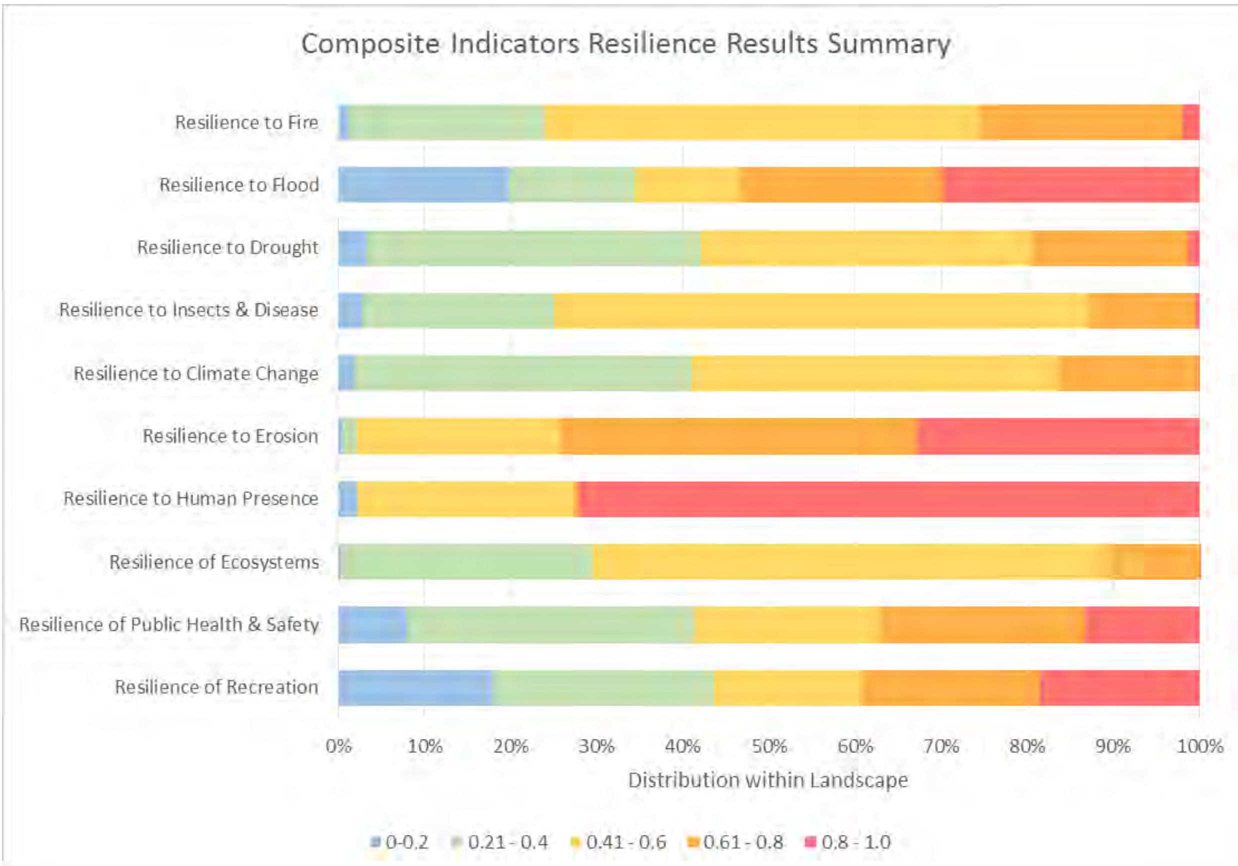

Figure 5. For each composite indicator, the percent area for each of the five resilience classes is displayed with colored bars. Values approaching 1 represent decreased resiliency.

- *Class 1 (0 – 0.2): High resilience*
- *Class 2 (0.21 – 0.4): Moderate resilience*
- *Class 3 (0.41 – 0.6): Less resilience*
- *Class 4 (0.61 – 0.8): Low resilience*
- *Class 5 (0.81 – 1.0): Least resilience*

A. Resilience to Fire

The results for this composite indicator follow a normal distribution, with the majority of the landscape (51%) characterized as less resilience and only 1% of the landscape would be considered as high resilience (Figure 5). The landscape trends towards values of lower resilience > 0.41 (Figure 5). There is resilience to fire in canyons and at lower elevations around the shore of Lake Tahoe (Appendix B, Composite A).

B. Resilience to Flood

Twenty percent of the landscape was ranked as having high resilience, with the majority of the landscape classified as least resilient (30%) (Figure 5). The landscape trends towards values of lower resilience >0.41 (Figure 5). Higher elevations and canyons have resilience to floods (Appendix B, Composite B).

C. Resilience to Drought

The majority of the landscape is ranks as having moderate and less resilience with 39% of the landscape being in each class, and only 3% of the landscape identified as having high resilience (Figure 5). The landscape trends towards values of resilience <0.6 (Figure 5). There is lower resilience to drought in canyons and at lower elevations around the shore of Lake Tahoe (Appendix B, Composite C).

D. Resilience to Insects & Disease

The majority of the landscape was identified as having less resilience (62%), with only 3% of the landscape ranked as having high resilience (Figure 5). The landscape trends towards values of resilience <0.6 (Figure 5). In general, resilience to insects and disease is evenly distributed across the landscape (Appendix B, Composite D).

E. Resilience to Climate Change

The majority (43%) of the landscape was identified as having less resilience and only 2% of the landscape was identified as having high resilience (Figure 5). The landscape trends towards values of resilience <0.6 (Figure 5). There is lower resilience to climate change in canyons and at lower elevations around the shore of Lake Tahoe (Appendix B, Composite E).

F. Resilience to Erosion

The majority of the landscape was identified as having low resilience (41%) and least resilience (33%). None of the landscape was identified as having high resilience (Figure 5). The landscape trends towards values of resilience >0.41 (Figure 5). There is lower resilience to erosion in canyons and at higher elevations around the shore of Lake Tahoe (Appendix B, Composite E).

G. Resilience to Human Presence & Activity

The majority of the landscape was identified as having the least resilience (72%) and only 2% of the landscape was ranked as having high resilience (Figure 5). The landscape trends towards values of resilience >0.41 (Figure 5).The majority of the landscape has very low resilience to human presence and activity, areas of higher resilience are found in more remote areas at higher elevations and within the wilderness (Appendix B, Composite G). This result is not surprising since the project area is a recreational destination.

H. Resilience of Ecosystems

The majority of the landscape was identified as having less resilience (60%). Importantly, none of the landscape is considered in a state of high resilience or least resilience (Figure 5). The landscape trends towards values of resilience <0.6 (Figure 5). There is lower resilience of ecosystems in canyons and at lower elevations around the shore of Lake Tahoe (Appendix B, Composite H).

I. Resilience of Public Health & Safety

The majority of the landscape was identified as having moderate resilience (33%) and 8% of the landscape as having high resilience (Figure 5). The landscape trends towards values of resilience <0.6 (Figure 5). There is lower resilience of public health and safety in canyons and at lower elevations around the shore of Lake Tahoe (Appendix B, Composite I).

J. Resilience of Recreation

Resilience classes are approximately evenly distributed across the landscape, with the majority of the landscape identified as having moderate resilience (26%) and 18% as having a high resilience (Figure 5).

The landscape trends towards values of resilience <0.6 (Figure 5). There is lower resilience of recreation in canyons and at lower elevations around the shore of Lake Tahoe (Appendix B, Composite J).

Summary

Each individual indicator provides a different perspective on landscape resilience. Six of the indicators evaluated less than 10% of the project (Figure 3), while all other indicators evaluated more than 50% of the project area. The majority of the indicators did not assess 100% of the landscape because they were focused on specific habitat types such as creeks, meadows, and forests. For example, creeks make up only 10% of the total landscape. Different indicators suggest that the majority of the landscape is resilient (6), less resilient (4), least resilient (5) (See table below), and one indicator had equal area of resilient and least-resilient (snowpack). For the proportional indicators, nearly all of the landscape was identified as least-resilient for seral stage and about half was suggested to be resilient for both vertical and horizontal heterogeneity.

Resilient	**Less Resilient**	**Least Resilient**
fire severity	trees per acre	mean condition class
meadow connectivity	climatic water deficit	meadow refugia
thermal tolerance	water quality	roads and trails linked to water channels
fire risk index	bark beetle predators	human access
floodplain condition		aquatic organism passage
native fish diversity		

Spatially, resilience varied based on the individual indicator (e.g. some indicators might say that an area is resilient, while other indicators would say it is least resilient). However, there were some general landscape patterns. Areas close to the shore of Lake Tahoe were resilient for meadow refugia (specifically in the southern area of the project) and water quality, while these areas were identified as least resilient for mean condition class, climatic water deficit, and snowpack. Areas in east-west canyons were resilient for water quality, and least resilient for fire severity, trees per acre, climatic water deficit, and fire risk index. Higher elevation and wilderness areas were resilient for trees per acre, thermal tolerance, snowpack, human access, were less resilient for mean condition class, and were least-resilient for meadow refugia, water quality, and bark beetle predators. The northern portion of the project area was least resilient for meadow connectivity and meadow refugia, while the southern portion of the project area was resilient for both of these indicators.

The intent of the composite indicators was to combine the individual indicators to identify potential hotspots where multiple indicators identified similar resilience. Each composite indicator needs to be evaluated separately since the composites often use the same indicators to evaluate resilience, many of the indicators are correlated, with 16 correlations greater than 0.5 (Figure 6).

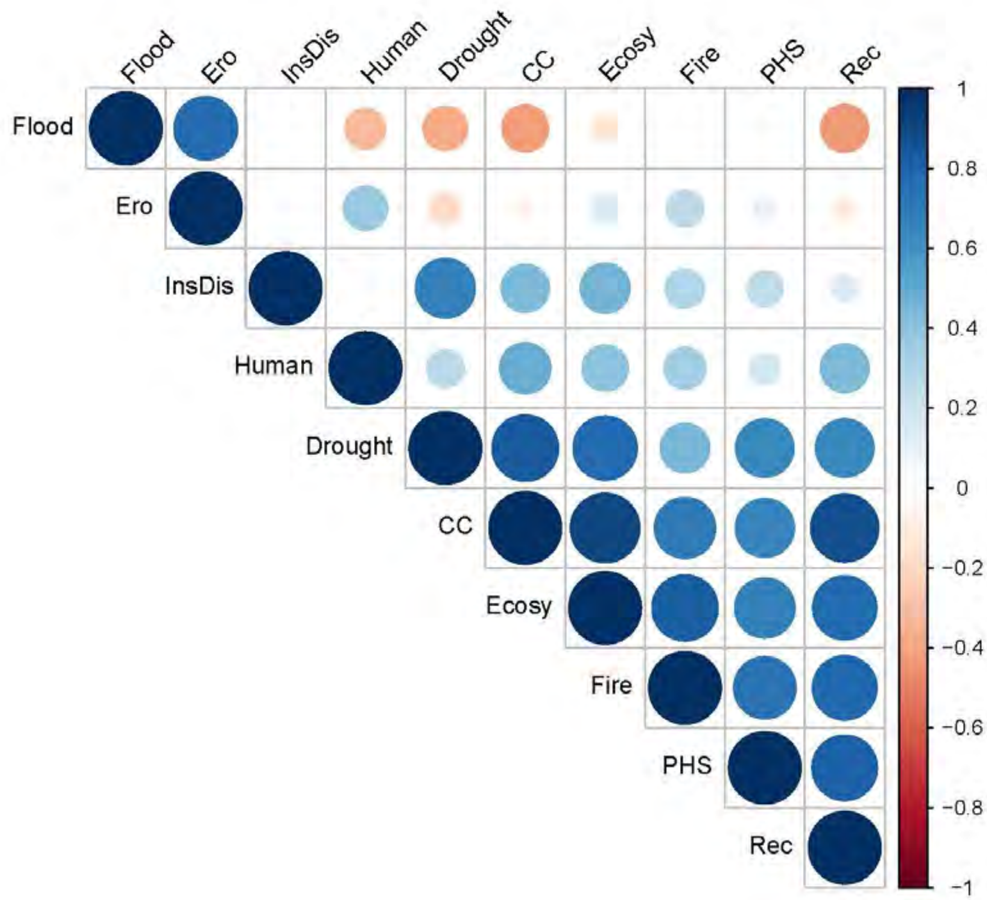

Figure 6. Correlation chart indicating correlations between composite indicators. The larger the circle, the greater the correlation. Blue circles indicate positive correlation, while orange circles indicate negative correlations.

Even though many of the composite indicators are highly correlated they all include a different combination of individual indicators and therefore provide a different perspective on the landscape resilience. Different composite indicators suggest that the majority of the landscape has moderate-resilience (2), less-resilience (4), low-resilience (1), and least-resilience (2). Since the majority of the composite indicators suggest the landscape is less resilient, the Design Team evaluated if the majority of the landscape falls within resilience values of 0 to 0.6 or within 0.41 to 1. Six composite indicators trend towards more resilience (<0.6: drought, insects and disease, climate change, ecosystems, public health and safety, recreation) and four composite indicators trend towards poorer resilience (>0.41: fire, flood, erosion, human presence and activity). Overall flood and recreation have the highest proportion of the landscape in high resilience, while human presence has the highest proportion in least resilience.

The majority of the composite indicators (eight out of ten) indicate that lower elevation areas (areas outside of the wilderness and closer to the shore of Lake Tahoe) and east-west canyons (e.g. Ward canyon) have lower resilience. However, it is important to recognize that many of these indicators are also spatially correlated. Regardless, lower elevations and east-west canyons may be important areas to prioritize for restoration to increase resilience. Higher elevation areas have less resilience to floods and erosion as a result of the steep slopes and natural soil conditions.

This landscape resilience assessment provides the foundation for the landscape restoration strategy. This assessment was developed based primarily on large spatial datasets, therefore it is important to evaluate on the ground conditions prior to developing specific projects. However, the assessment can guide priority areas to evaluate the need for restoration activities, thereby minimizing field-based efforts in the large landscape. Both individual and composite indicators can begin to guide priority areas for restoration. In addition, the data was developed so that additional composite indicators could easily be developed to evaluate specific questions. For example, a composite specific to the modeling effort in LTW Phase 2 may be desired in order to represent probability of treatment on the landscape, to feed into the science modeling component of the Lake Tahoe West project. The advantage of this approach would be to use only indicators that would be modeled by the science team. Another example would be to develop a spotted owl specific composite indicator to be evaluated within the spotted owl Protected Activity Centers. Here are three examples of how the strategy team could use both individual and composite indicators to guide restoration, however these are just examples and there are numerous approaches to incorporate this information into the strategy:

1) prioritize restoration in Protected Activity Centers where the composite indicator for resilience to human presence suggests lower resilience;
2) prioritize forest thinning/fuels treatments in areas where composite indicators for resilience to fire and resilience to insects and disease suggest lower resilience; and
3) evaluate meadow condition in meadows that are identified as resilient based on the individual meadow refugia indicator in order to prioritize restoration activities in areas that will be more resilient to future climate.

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Appendices

Appendix A – Additional Indicator Information

Appendix B – Individual and Composite Indicator Resilience Maps

Appendix C – Indicators-Disturbances-Values Table

Appendix D – Removed Indicators

Appendix E – Next Steps, Future Updates to Existing Indicator

Appendix A – Additional Indicator Information

Contents

This appendix contains additional information for some, but not all, of the indicators as well as for composite indicators. For some indicators, there was a need to further explain the rationale behind the desired resilient condition, provide more details regarding the data sources and modifications to the data, and/or discuss constraints in the analysis. Overall, this appendix serves to provide the reader with a closer look at certain indicators in order to present a full picture of methodologies and caveats.

Indicators Assigned a Resilience Value

Fire Severity

Table A-1 High severity fire patch size thresholds and sources of information.

Vegetation Type	Data Source			
	LTBMU Forest Plan (USDA 2016)	Beaty and Taylor (2008)	Region 5 BioRegional NRV reports	Comments
Jeffrey Pine	<5 ac Rare and extreme events may include larger patches	Small lower slopes Larger upper Density generally decreases with increasing slope position. This should support creating fire mgt containers	Mean 1.4 ha (3.5 ac), max 16 ha (40 ac) Rarely larger	It was noted the large patches did occur historically (Beaty and Taylor 2008). The Forest Plan and NRV noted that rare and extreme conditions could lead to larger patches
White fir	<10 ac Rare and extreme events may include larger patches	Same as above	Mean 1.4 ha (3.5 ac), max 16 ha (40 ac) Rarely larger	Same as above
Red fir	<10 ac Rare and extreme events may include larger patches	Same as above	Mean <10 ha (25 ac) Up to 30 ha (74 ac)	Same as above

The ranges in Table A-1 were derived from the LTBMU Forest Plan (USDA 2016), Beaty and Taylor (2008), and USFS Region 5 Natural Range of Variation (NRV) reports produced by the Ecology Group (Pacific Southwest Region Ecology Program Documents, Reports, and Publications at https://www.fs.usda.gov/detail/r5/plants-animals/?cid=stelprdb5434436). The NRV reports reference many other sources of information and would therefore be a good reference for any reader wishing additional information. Although the high severity patch size thresholds derived from these data sources are desired, we understand that acceptable threshold may be larger in order to facilitate management strategies that use fire. Indeed, the literature reviewed and LTBMU Forest Plan (USDA 2016) state that larger patch sizes do occur, but are the exception, not the rule. Therefore, patches larger than those in the table are acceptable, although not targeted. Larger patch sizes of high severity fire can be acceptable if still a small proportion of a larger fire area. For our range of resilient condition, we selected the highest published value for Jeffrey Pine and White Fir patch size.

We used Fire Simulator (FSim) outputs to evaluate fire severity. The modeled outputs were at a 120m meter resolution (~8 acre pixels). We reclassified the modeled outputs based on assuming that anything over an 6 foot flame length would be moderate to high severity (we included the following flame intensity lengths that are all greater than 6ft: FIL4, 5, and 6). We then used a majority filtering on the raster dataset to develop high severity polygons to evaluate patch size. All polygons that were greater than 40 acres had a one, everything else was assigned a zero.

The Risk Assessment GTR was published first. Then the Southern Sierra was done before the Northern Sierra, and the process was published (citation 2 below). The northern Sierra followed the same process with no publication. HOWEVER, we only used the FSIM outputs from the Northern Sierra Risk Assessment for the LRA, not the whole assessment. The FSIM model is described in the 3rd citation.

1. Scott, Joe H.; Thompson, Matthew P.; Calkin, David E. 2013. A wildfire risk assessment framework for land and resource management. Gen. Tech. Rep. RMRS-GTR-315. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 83 p.
2. Thompson, M., Bowden, P., Brough, A., Scott, J., Gilbertson-Day, J., Taylor, A., Anderson, J., Haas, J., 2016. Application of Wildfire Risk Assessment Results to Wildfire Response Planning in the Southern Sierra Nevada, California, USA. Forests 7, 64. doi:10.3390/f7030064
3. Finney, M.A., McHugh, C.W., Grenfell, I.C., Riley, K.L., Short, K.C., 2011. A simulation of probabilistic wildfire risk components for the continental United States. Stoch. Environ. Res. Risk Assess. 25, 973–1000. doi:10.1007/s00477-011-0462-z

Additional methodological details built into High Severity

- Evaluated different probability thresholds (0%, 5%, 20%) and stuck with any probability of burning at high severity was less resilient to uncharacteristic high severity fire and the related effects to other values.
- Majority filter on the raster dataset – using 4 nearest neighbors
- An evaluation of the weather data (RAWS) used in the Northern Sierra Risk Assessment and comparison with local data lead to the recognize FSIM likely underestimated fire severity on landscape.

Data Sources in More Detail (How Table A-1 was developed)

- **LTBMU Forest Plan (USDA 2016)**

  Jeffrey pine -- **Except in extremely rare events**, contiguous areas of crown mortality after fire are less than 5 acres in size. High severity patches are principally confined to higher density, closed canopy stands and/or warm, upper slopes.

  White fir-Mixed conifer -- **Except in rare events**, contiguous areas of crown mortality after fire are less than 10 acres in size. High severity patches are principally confined to higher density, closed canopy stands and/or warm, upper slopes.

  Red fir -- **Except in rare events**, contiguous areas of crown mortality after fire are less than 10 acres in size. High severity patches are principally confined to higher density, closed canopy stands and/or warm, upper slopes. Where this type overlaps the WUI, fires occur as surface fire due to fuels treatments.

- **Beaty and Taylor (2008)**

  Reference: Beaty, R.M. and Taylor, A.H., 2008. Fire history and the structure and dynamics of a mixed conifer forest landscape in the northern Sierra Nevada, Lake Tahoe Basin, California, USA. *Forest Ecology and Management*, *255*(3), pp.707-719.

  This research used fire scars, age cores and chronologies, topographic position, and climate variability to try to tease out factors most responsible for fire characteristics as well as fine and coarse grain vegetation patterns in the General Creek WS (GCW). Most previous studies found frequent, low-severity fire dominating these mixed conifer systems. This paper suggest the picture is more complicated. They suggest forest structure-fire relationships are more complex due to the influence of landscape and regional controls such as topography, climate variability, and human use practices. The fire-vegetation relationships are more difficult to tease out recently because they are obscured by human use practices. This paper examines how topographic and climatic variation contribute to spatial and temporal variability in fire regimes and forest structure.

  Rather than assessing fire effects at the stand scale like most other studies, and perhaps picking up the 5-17 year fire return interval (FRI), this paper looks at an entire watershed and stratifies the sites by topographic position. They found that large patches of even-aged forest are embedded in the old forest matrix, which suggests some level of high severity fire.

  Beaty and Taylor (2008) found that most fire occurred in the dormant season, similar to other Northern Sierra and Southern Cascade regimes. This is in contrast to the Sierra San Pedro Martir (SSPM) where most fires occur during the growing season, and Southern Sierra where about half occurred in the growing season. They suggest that the seasonal shift is due to southern areas getting an earlier start to the fire season.

  Most of the high severity fire effects were found on the upper slopes, and low severity on the lower slopes, and mid-severity on mid slopes. The authors hypothesized that on lower slopes and valley bottoms, frequent low severity fires kill smaller and younger trees, while sparing the large, thick-barked trees. This differentiation in fire severities by slope would promote uneven-aged stands that are open. Regeneration occurs in small overlapping patches. On upper slopes, high severity fire creates coarse grained stands of chaparral, or even-aged patches of trees in sharp contrast to lower and mid. These results suggests structural heterogeneity is promoted by topographic position and fire severity.

- **Region 5 Natural Range of Variation Reports**
  - Yellow Pine-Mixed Conifer NRV (9/2/2015)

    High severity patches more than a few hectares in size were relatively unusual (although not unknown) in fires in Sierra Nevada Yellow Pine Mixed Conifer forests before Euroamerican settlement. The natural range of variation (NRV) of high fire-severity patch size in the assessment area was strongly dominated by a fine-scale pattern of small areas less than a few hectares in size. Larger patches than a few hectares did occur, but they were rarely more than 100 ha in size.

  - Red Fir NRV

The Illilouette Creek Basin in Yosemite National Park is perceived as a reference ecosystem for LTW. The Park has been managing wildfires for resource benefits for decades. Assessments of recent fire severity patterns reveal that the mean patch size of stand-replacing, high-severity burned patches (>95% tree mortality) following the Hoover Fire (2001) and Meadow Fire (2004) was 9.1 ha (median = 2.2 ha; Collins and Stephens 2010). More than 60% of the stand-replacing patches in their study were ≤4 ha in size, but a few large patches accounted for ~50% of the total stand-replacing patch area.

Miller et al. (2012) found that lower and upper montane forests (including red fir forest) had a mean patch size of 4.2 ha (11.4 ac)in Yosemite National Park.

Trees per Acre

The acceptable resilient conditions for trees per acre were based on literature described at the bottom of this section. While the results presented in the LRA and the desired condition based literature tends to skew towards trees larger than 10", LiDar does capture smaller trees as well. Therefore, this assessment is for all size classes of trees (does not include saplings or seedling).

Data for trees per acre came from EcObject LiDAR data for trees per acre. We adjusted the acceptable resilient condition for LiDAR data based on field plot data, because LiDAR assessment of trees per acre suffers from both commission and omission errors. These errors are because LiDAR has difficulty capturing smaller diameter trees in the forest understory. In general, the LiDAR data underestimate smaller trees, especially those with a diameter-at-breast-height (DBH) under 10 inches. In order to account for this underestimation the IADT compared the LiDAR plot data from Vegetation Sheds that intersected with the LTW project boundary to the LiDAR data in the same plot footprint. These plot data were collected using a Javad GPS unit (cm accuracy) so there is confidence that the same footprint was compared. The IADT had a total of 10 plots with which to make a comparison. The IADT investigated the difference between the ground-based plots and LiDAR "plots" for all trees, trees >10" DBH, and trees > 5" DBH (Table A-2). Based on these data, and because LiDAR data in general are better at capturing trees > 10" DBH, we adjusted our acceptable resilient condition values to evaluate TPA based on the maximum difference in trees >10" DBH (e.g. we reduced upper values by 30 trees) (Table A-3).

Table A-2 Comparison between Lidar "plots" and ground-based verification plots. Table present the difference for all trees, the difference for trees greater than 10" DBH and the difference for trees greater than 5" DBH. The minimum, maximum, and average are also presented.

Row Labels	All Tree Difference	10" Difference	5" Difference
LT143	40	20	20
LT145	2	3	3
LT170	7	9	9
LT240	10	9	9
LT336	16	12	12
LT436	-4	13	13
LT466	1	-9	-9
LT556	10	6	6
LT638	56	28	28

LT639	83	30	30
LT739	42	8	8
LT750	22	16	16
LT837	28	15	15
Min	-4	-9	-9
Max	83	**30**	30
Average	20.84615385	12.30769231	12.30769231

Table A-3 Acceptable resilient condition for Trees Per Acre adjusted to apply the data to EcObject Lidar data.

Type	High Resilience (0)	High Resilience (0) for LiDAR adj	Mid Resilience (0.5)	Mid Resilience (0.5) for LiDAR adj	Not Resilient (1)	Not Resilient (1) for LiDAR adj
Jeffrey pine	0-60	0-30	60-130	30-100	>130	>100
White fir – mixed conifer	0-55	0-25	55-100	25-70	>100	>70
Red fir	0-80	0-50	80-247	50-217	>247	>217
Subalpine	<140	<110	N/A	N/A	≥140	>100
Aspen	<200 SDI	<200	200-400 SDI	200-400	>400 SDI	>400

Literature supported TPA ranges used for resilience ranges:

Table A-4 Jeffrey Pine Forest Trees/Acre

Mean trees/acre[1]	**Range trees/acre[1]**	**Source**	**Location**	**Notes**
59	12-130	Stephens and Gill (2005)	Sierra San Pedro Márir	Reference site – 49 1-ha plots current day
62		Safford (unpublished)	Sierra San Pedro Márir	Reference site – larger sample than Stephens and Gill current day
87		Safford (unpublished)	Sierra Juarez	Reference site – current day
28	12-46	Taylor 2004 and Taylor et al. 2014	Lake Tahoe Basin (east shore)	≥10cm dbh
27		North et al. 2007	Teakettle (Sierra NF)	≥5cm dbh
133	*note no upper range provided	Lyderson et al. from Safford 2013		≥10cm dbh
65		Scholl and Taylor 2010	Yosemite NP	≥10cm dbh Having a hard time finding ref

Mean trees/acre[1]	Range trees/acre[1]	Source	Location	Notes
40		USDA 1911 from Safford 2013		≥15.2cm dbh
24		Collins et al. 2011	Yosemite NP	≥15.2cm dbh
87 & 95		Parsons and Debenedetti 1979	Sequoia and Kings Canyon NPs	No Jeffrey pine, lower elevation, oaks present ≥12cm dbh.
200-early 70-mid 60-late 15-old	15-200 depending on seral stage	LTBMU Forest Plan 2016		Desired conditions for JP forest composition for all Forest
[1] Most data given in trees/ha. Divided those numbers by 2.47 to get trees/ac because 1 ha = 2.47 acre.				

Table A-5 White fir- mixed conifer Trees/Acre

Mean trees/acre[1]	Range trees/acre[1]	Source	Location	Notes
53	22-102	Taylor et al. 2014	Sugar Pine Point State Park, Lake Tahoe	NOTE: Safford 2013 classifies this as yellow pine in the NRV paper but Taylor et al. 2014 classify as mixed conifer. 12 sites; ≥5cm dbh mixed conifer forests may be co-dominated by incense cedar, sugar pine, Jeffrey pine, red fir, western white pine, or white fir – compares to other estimates that are actually provided above as yellow pine forests.
300-early 100-mid 80-late 25-old	25-300 depending on seral stage	LTBMU Forest Plan 2016		Desired conditions for white fir – mixed conifer forest composition for all Forest
[1] Most data given in trees/ha. Divided those numbers by 2.47 to get trees/ac because 1 ha = 2.47 acre.				

Table A-6 Red fir Trees/Acre

Mean trees/acre[1]	Range trees/acre[1]	Source	Location	Notes
66	48-84	Taylor 2004 and Taylor et al. 2014	Lake Tahoe, east shore	≥5cm dbh
300-early 100-mid 80-late 25-old	25-300 depending on seral stage	LTBMU Forest Plan 2016		Desired condition for red fir on all Forest lands

Mean trees/acre[1]	Range trees/acre[1]	Source	Location	Notes
173	73-247	Stephens 2000 using data from Sudworth 1899 field notebooks	Southern portions of Tahoe NF and El Dorado NF, northern portion of Stanislaus (and Safford 2013 says SLT too?)	Trees greater than 28cm
212 (estimated from bar graph)		Meyer NRV		Sources used in Meyer calculation include: Bekker and Taylor 2001, Taylor and Solem 2001, van Wagtendonk 1985, Miller et al. 2012, Mallek et al. in review
[1] Most data given in trees/ha. Divided those numbers by 2.47 to get trees/ac because 1 ha = 2.47 acre.				

Subalpine Trees/Acre

See figure below from *The Natural Range of Variation of Subalpine Forests in the Bioregional Assessment Area* written by Marc Meyer. This figure is based on data from Dolanc et al. (2013).

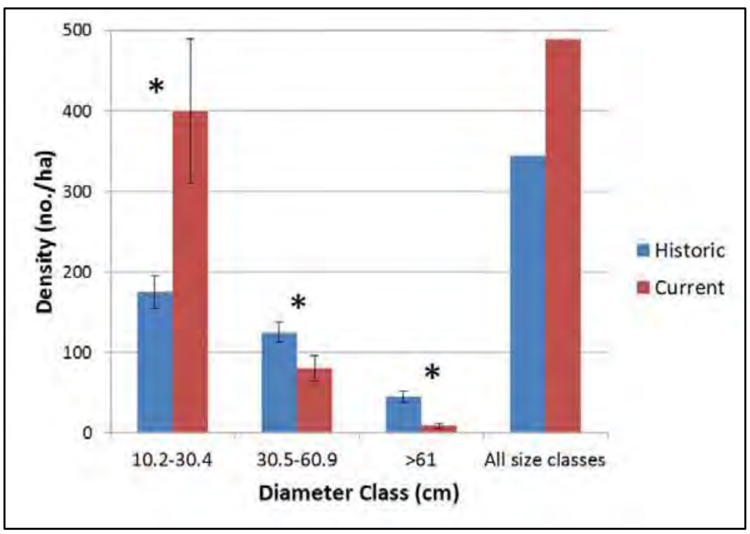

Figure A-1 Trees per Acre vs Diameter Class (cm) for Historic and Current Conditions

Aspen Trees/Acre

The goal is to have an SDI ≤ 500 for highly vigorous aspen stand; don't let aspen SDI exceed 1000. Goal is also to have stand with ≥ 60% aspen represented (Berrill and Dagley pers. comm. 2017). Note: SDI was changed to English units in DC table.

Riparian Trees/Acre

84 trees/acre source: Van De Water and North 2011 (Lassen NF, Onion Creek Experimental Forest, and Lake Tahoe Basin).

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Meadow Refugia and Meadow Connectivity

Table A-7 Refugia Meadow resilience ranking

Refugial meadows	**Resilience ranking**
No refugia status	1
Refugia tminbeg or AnnPrecip	0.5
Refugia both tminbeg and AnnPrecip	0

Table A-8 Meadow connectivity resilience ranking

Refugial meadows with connectivity rankings[1]	**Meadow connectivity resilience Rank**
RC (really well connected)	0
WC (well connected)	0.5
LC (least connected)	1
[1] *Source: Morelli, T.L., C. Daly, S. Z. Dobrowski, D. M. Dulen, J. L. Ebersole, S. T. Jackson, J. D. Lundquist, C. I. Millar, S. P. Maher, W. B. Monhan, K. R. Nydick, K. T. Redmond, S. C. Sawyer, S. Stock, S. R. Beissinger. 2016. Managing climate change refugia for climate adaptation. PLOS ONE: DOI:10.1371/journal.pone.0159909 August 10, 2016.*	

The IADT evaluated four future climate models from Maher et al. 2017 to see which indicators showed a difference for refugia. The assessment was focused on indicators that had most difference between refugia and not refugia meadows (Tables A-6 and A-7).

Table A-9 Comparison of the four climate models for the following metrics: Snow Water Equivalent (swe), Climatic Water Deficit (cwd), Annual Precipitation (AnnPrecip), Temperature (T, t). Note that the terms “beg”, “end”, and “mid” indicate beginning (2010-2039), ending (2070-2099), and middle time periods (2040-2069).

Model	**Metric**	**Number of meadows that have a Resilience Ranking of 1 (i.e., refugia meadow) – out of 94 total meadows**
PCM_B1	TmaxM_beg	68
GFDL_B1	AnnPrecip2	51
GFDL_B1	tminbeg_60	51
PCM_A2	tinbeg60	46
PCM_A2	swe_beg	45
PCM_B1	swe_mid	39
PCM_B1	tminbeg60	35
GFDL_A2	swe_mid	35

Model	Metric	Number of meadows that have a Resilience Ranking of 1 (i.e., refugia meadow) – out of 94 total meadows
GFDL_B1	SWE_beg	34
PCM_B1	swe_end	33
GFDL_A2	swe_beg	33
GFDL_A2	tminbeg60	33
GFDL_A2	AnnPrecip	31
PCM_A2	tmaxM_beg	26
GFDL_B1	AnnPrecip1	21
GFDL_B1	SWE_mid	21
PCM_A2	swe_mid	13
PCM_B1	swe_beg	7
GFDL_A2	TmaxM_beg	7
GFDL_B1	TmaxM_Beg	6
PCM_B1	AnnPrecip1	3
PCM_A2	AnnPrecip_	3
GFDL_B1	AnnPrecip	3
PCM_B1	CWD_beg	1
PCM_B1	cwd_mid	1
PCM_B1	cwd_end	1
PCM_A2	cwd_beg	1
PCM_A2	cwd_mid	1
PCM_A2	cwd_end	1
GFDL_B1	CWD_beg	1
GFDL_B1	CWD_mid	1
GFDL_B1	cwd_end	1
GFDL_B1	SWE_end	1
GFDL_A2	AnnPrecip1	1
GFDL_A2	cwd_beg	1
GFDL_A2	cwd_mid	1
GFDL_A2	cwd_end	1
GFDL_A2	swe_end	1

Table A-10 Comparison between four climate models (GFDL_A2, GFDL_B1, PCM_A2, PCM_B1) for top refugia status.

GFDL_A2	GFDL_B1	PCM_A2	PCM_B1
AnnPrecip	AnnPrecip1	swe_beg	swe_end
swe_beg	AnnPrecip2	swe_mid	swe_mid
swe_mid	swe_beg	tminbeg60	TmaxM_beg
tminbeg60	swe_mid	TmaxM_beg	tminbeg60

	tminbeg_60		

The IADT evaluated all of the different metrics for the different models to evaluate results of the meadows in the analysis area in order to identify metric and models that had some variation to display on the landscape.

The IADT focused on using GFDL_A2 climate scenario (warmer and drier) because A2 is business as usual and is more likely than the B1 scenario. The IADT then used a combination of temperature and precipitation to select refugia meadows because the metric "swe" is correlated with both precipitation and temperature.

Appending to EcObject

Due to the small size of meadows, Maher et al. (2017) buffered the meadow dataset (Fryjoff-Hung and Viers 2012) by 150 meters. In order to apply this information back to EcObject and avoid capturing buffered polygons the IADT did the following:

- Select meadows that have their centroid within the refugia meadow layer (meadow dataset) and transfer resilience rank to these,
- Select EcObjects that have centroids in meadow and transfer resilience rank to EcObject,
- And these steps resulted in
    - two areas analyzed that do not show up as meadows,
    - some meadows in the updated meadow layer were not included in the original meadow dataset used in Maher et al. (2017) analysis and therefore will have a null value for these indicators,
    - and some sections of meadows were omitted where the centroid of EcObject doesn't overlap – however the majority of each meadow was always captured by >1 EcObject .

Methodology/logic for selecting range of values for acceptable resilient conditions

Relevant information **copied** from: Maher et al. (2017)

"Connectivity was not a consistent predictor of refugial status in the 20th century, but expected future climate refugia tended to have higher connectivity than those that recently deviated from historical conditions. Climate change is projected to reduce the number of refugial meadows on a variety of climate axes, resulting in a sparser network of potential refugia across elevations. Our approach provides a straightforward method that can be used as a tool to prioritize places for climate adaptation.

Connectivity can also increase the risk of invasion, spread, and persistence of pests and pathogens (Schreiber and Lloyd-Smith 2009, Maher et al. 2012),

We compare patterns of connectivity based on four hypothesized factors that could affect isolation of meadows: distance, topography, watercourses, and roads. Next, we identify which meadows were climate refugia based on a suite of variables, including temperature, precipitation, and water balance.

Classified meadows that were in the upper quartile of connectivity in all surface measures as "well connected" (WC), using R ver. 3.0 (R Core Team 2013). Meadows that were in the upper quartile of at least one, but not all of the seven surfaces (watercourses 9 4, elevation, roads, and the uniform distribution), were classified as “more connected” (MC), and the remaining meadows were considered “least connected” (LC).

We defined climate refugia as areas on the landscape where the magnitude of change in climate and climate-derived measures was minimal, as measured from a baseline period of 1910–1939 compared to modern climate 1970-1999

We used the following three thresholds to define minimal change in climate conditions: (1) temperature changes within 1°C; (2) relative precipitation, snowpack, and CWD changes within 10%; and (3) no more than 1 or 2 months/yr on average exceeding the extreme historical temperature and precipitation variation, respectively.

We added additional complexity by classifying meadows as refugial if they also met threshold conditions for two environmental axes: (1) mean annual temperature and mean annual precipitation and (2) 1 April SWE and extreme monthly minimum temperature (1 month/yr threshold). While these criteria were not based on statistical models, they identified sites undergoing little change.”

Scenario selection for future climate modeling:

- A2 represents a business-as-usual scenario that assumes little mitigation,
    - yielded very few refugial meadows by the end of the 21st century
    - number of refugia designated by temperature measures decreased in each time step, regardless of connectivity and quantitative approach
- B1 includes reduced future emissions and
    - number of refugia classified on the basis of precipitation changed inconsistently through time, as there were differences between the measure of central tendency and the number of extreme months.
- With two general circulation models PCM and GFDL (the NCAR Parallel Climate Model [PCM] and the NOAA Geophysical Fluids Dynamics Laboratory [GFDL]).

Range of projected climatic conditions in California:

- warmer and wetter (PCM B1 and GFDL B1)
- warmer and drier (PCM A2 and GFDL A2).

Time periods to select:

- early (2010–2039),
- middle (2040–2069),
- late 21st century (2070–2099)

Literature Cited

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Thermal Tolerance

The Southwest Climate Science Center (SWCSC) climate extreme project is supported by the Southwest Climate Science Center (US Geological Survey) and University of California, Davis. The project had three complementary parts. The SWCSC climate extreme group screened regional downscaled climate models on the basis of their ability to represent regional (as opposed to national) extremes, they developed a platform for delivery of climate data that allows users to customize what the models derive, and they collaborated with small teams of managers to apply data on extremes to decision-making.

The California Spotted Owl is sensitive to temperatures at or above 30^0C. At temperatures at or above 30^0C body temperature elevates and body width index (piloerection) increases. At temperatures at or above 32^0C breathing rate increases. At temperatures at or above 34^0C, gular fluttering, gaping, and drooping of the wings occurs. The up-per critical temperature for the California Spotted Owl is 35.2^0C, where resting metabolic rate increased exponentially (Weathers et. al 2001).

The climate extreme group processed an ensemble of statistically downscaled (6 km resolution, based on gridded interpolations from station observations) GCM simulations using the localized analog statistical downscaling method (LOCA; http://loca.ucsd.edu/). The climate extreme group then derived climate extreme metrics based on two Representative Concentration Pathways (RCP) emission scenarios and ten climate models. The total number of days between May through September where the daily maximum temperature exceeded CA Spotted Owl threshold temperatures (30^0C, 34^0C, and 35.2^0C) was calculated for each grid cell. Raster data were produced based on the median value of the ten model results at each LOCA grid-point in California for each emission scenario and each year from 1985 to 2025. The resulting data were produced at the state scale, which can provide information on potential suitable temperature locations outside of the existing distribution.

We used data for the 2025 projected median value of the total number of days between May through September for which the daily maximum temperature exceeded the threshold temperature of 30°C based on an ensemble of 10 global climate models and the RCP 4.5 emission scenario. The total number of days between May through September where the daily maximum temperature exceeded CA Spotted Owl threshold temperatures (30^0C, 34^0C, and 35.2^0C) was calculated for each grid cell. These data were rated for resilience based on Jenks natural breaks (a data clustering method designed to determine the best arrangement of values into different classes), rounded to whole numbers (see table below).

This dataset is available for managers to evaluate and utilize during decision making. An example is provided (below) of how the dataset may be used to show if and where the number of days crossing critical thresholds is increasing or is projected to increase over time. The current spotted owl distribution was determined using USGS National Gap Analysis Program distribution data for the CA spotted owl https://gapanalysis.usgs.gov/species/data/download/.

The datasets developed can be accessed internally through the Forest Service Network at: T:\FS\NFS\R05\Program\Ecology\GIS\RegionWide\SpottedOwlClimateExtreme.

LTW Data Used: We used data that show the 2025 projected median value of the total number of days between May through September for which the daily maximum temperature exceeded the threshold temperature of 30°C based on an ensemble of 10 global climate models and the RCP 4.5 emission scenario.

Table A-11 This data was rated for resilience based on Jenks natural breaks, rounded to whole numbers:

Thermal Tolerance Natural Break	Resilience Rank
0-5	0
5-13	0.25
14-19	0.5
20-26	0.75
27-42	1
*0.75 is within the analysis area, but not in the project area; 1 is just outside the analysis area. The dataset for the state of California goes to 146.5.	

Climatic Water Deficit

Climatic Water Deficit (CWD) is a measure of plant stress. It is calculated as the difference between actual and potential evapotranspiration, which is limited by soil moisture availability. We used climatic water deficit from the California Basin Characterization Model (BCM) models (Flint, Lorraine E., Alan L. Flint, org: USGS). This dataset provides historical and projected climate and hydrologic surfaces for the the state of California and all the streams that flow into it. The model has been calibrated using a total of 159 relatively unimpaired watersheds for the California region. We used historical data for the 2015 drought, which is based on 800m PRISM data spatially downscaled to 270 m using the gradient-inverse distance squared approach (GIDS). The BCM model uses a regional water balance model based on precipitation, temperature, elevation, geology, and soils to produce the variables in the model. In this case CWD and April 1st snowpack (see following indicator). Please see: http://climate.calcommons.org/article/featured-dataset-california-basin-characterization-model for additional information. However, we did not use the data available at the above website, we got the most current BCM data from a collaborator on a different project and extracted information for 2015. We summed the monthly the monthly CWD raster data for the 2015 water year.

Recent work has shown that drought induced beetle mortality is driven by a combination of drought stress and trees per acre. Climatic water deficit has shown clear strong relationships between forest mortality patterns and climatic water deficit (Restaino et al. submitted). We chose to focus our analysis on 2015 only, because it represents a drought year where CWD becomes important. The average historic CWD that is part of the EcObject dataset did not elucidate patterns of where drought stress may be most extreme. We based our thresholds of resilience on Restaino et al. (submitted). The raster was resampled to 5 meters and the majority value was appended to each EcObject.

Literature Used

Bark beetle-induced tree mortality is mediated by forest thinning and moisture availability in forests of the Sierra Nevada, USA by Restaino, Christina; Estes, Becky; Gross, Shana; Wuenschel, Amarina; Meyer, Marc; Safford, Hugh; Thorne, James Article reference: ERL-104399. Environmental Research Letters. Submitted 10/06/2017.

Snowpack

See Climatic Water Deficit for additional information.

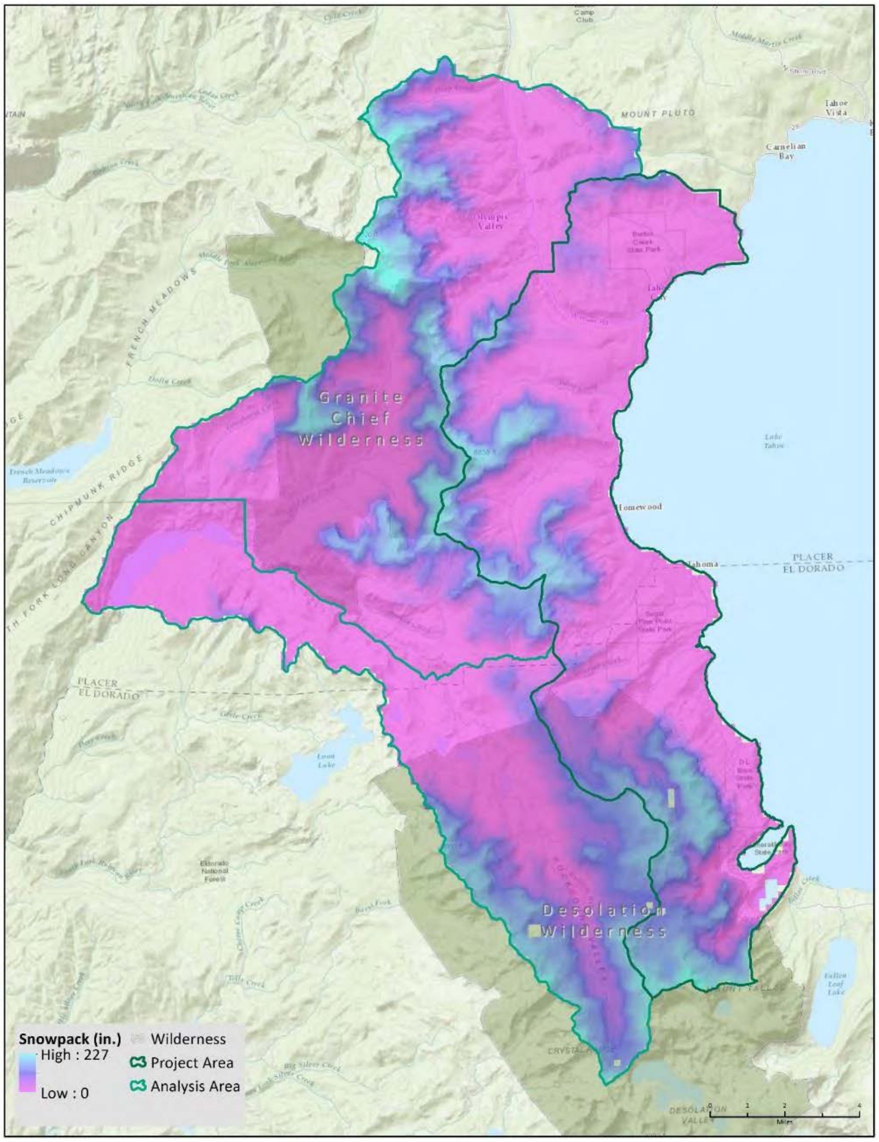


Figure A-2 Snowpack on April 1, 2015 in the LTW project area.

Fire Risk Index

The Modified Fire Risk Index measures the relative risk of human populations and infrastructure (values at risk) to the threat of wildland fire. The fire risk index combines an estimate of the probability of an area being threatened by wildfire (fire threat) and an estimate of the values that would be damaged by a wildfire at the predicted severity (fire effects).

The Modified Fire Risk Index measures the relative resilience of the public health and safety values to wildland fire. The Fire Risk Index was developed through the West Wide Wildfire Risk Assessment Project in 2014. It combines inputs including the locations of human populations and infrastructure, probability of ignitions, probable fire behavior, historic weather patterns, and local suppression capability. The Fire Risk Index is then weighted by the canopy cover slices from EcObject and LANDFIRE vegetation condition class.

The canopy cover slice data enables FRI to increase based on the presence of ladder fuels. This means that an area that received a treatment to reduce ladder fuels would receive a lower FRI score than an equivalent area that had not been managed to remove ladder fuels. This gets at the ability to modify these values based on management activities that occur.

The vegetation condition class data brings in additional outside data through LANDFIRE. It enables FRI to increase in areas where existing vegetation departs from historical simulated conditions. This allows identification of areas where trees and other vegetation can be managed to reduce fire risk.

Inspection of the FRI data revealed that areas in the vicinity of Ward Canyon showed relatively low FRI values not commensurate with other areas that subjectively face similar or lower levels of risk. Examination of the source data revealed that human populations and infrastructure in these areas were not included in the analysis.

To correct the dataset FRI values were sampled at 0, 0.25, 0.5, 0.75, and 1.0 miles from structures in four representative communities to reveal the influence that distance from structures has on FRI values. An exponential regression function was then developed and applied to increase FRI surrounding development in Ward Canyon.

FRI values are relative to other areas in the landscape, therefore the acceptable resilient conditions were defined based on quantiles, and then compared to established Wildland-Urban Interface boundaries.

The boundaries of the threat and defense zones were established with input from communities and fire professionals. The defense zone represents areas of greatest community and firefighter concern for protecting communities from wildfire. It typically extends approximately one quarter mile from vulnerable development and infrastructure, but can be extended or reduced based on site-specific conditions. Shaded fuel breaks at least one quarter mile in width typically provides an adequate buffer allowing high intensity fires moving toward a community to reduce in intensity and transition from a crown fire to a surface fire.

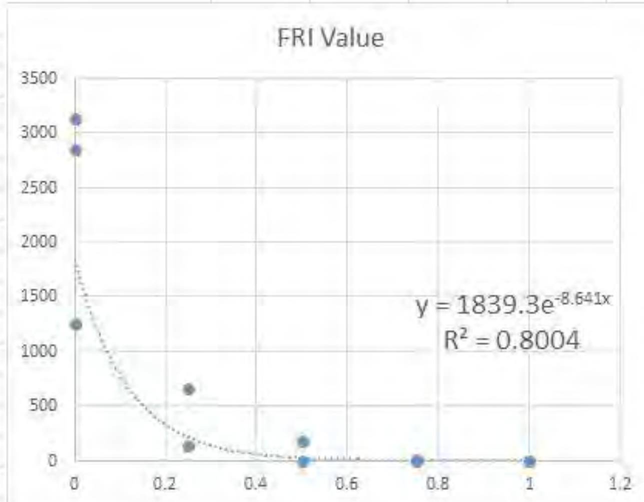
The half of the landscape with the lowest FRI values are considered acceptably resilient. The half of the landscape with the highest FRI values are considered mid-resilient or non-resilient.

Comparison of the categories of resilience to the Wildland-Urban Interface boundaries within the Lake Tahoe Basin revealed that the majority of non-resilient areas fall within the defense zone. Additionally, non-resilient and mid-resilient areas fall occasionally outside of the defense zone, indicating areas in the threat zone and general forest which impact the resilience of public health and safety to wildland fire.

See two tables below.

Modifiers for Fire Risk Index values near Ward Canyon

Distance from Development (miles)	FRI Value
0	2848
0.25	134
0.5	0.49
0.75	0.43
1	0.52
0	1249
0.25	659
0.5	180
0.75	11
1	0.66
0	3127
0.25	53
0.5	43
0.75	83
1	42
0	1796
0.25	354
0.5	151
0.75	99
1	107



Distance from Development (miles)	Modifier [=1839.3*EXP(-8.641*X)]	Additive Modifer	
0	1838.97	1063.84	
0.1	775.14	448.47	
0.2	326.67	189.00	
0.3	137.67	79.65	
0.4	58.02	33.57	
0.5	24.45	14.15	
0.6	10.30	10.30	
0.7	0	0	*Greater variance in FRI
0.8	0	0	values above 0.6 miles
0.9	0	0	indicated less influence from
1	0	0	structures.

10th Percentile Breaks	Percentile
0	10
0.29	20
0.96	30
2.32	40
5.07	50
12.34	60
35.79	70
120.84	80
487.75	90
>487.75	100

Range	Category	Value	Percentile
< 5.07	Resilient	0	0-50
5.07-120.84	Mid-Resilient	0.5	50-80
> 120.84	Not Resilient	1	80-100

Roads and Trails Linked to Water Channels

Figure A-3 Spatial data used to evaluate resilience of road and trail crossings.

Water Quality

Data used for this indicator is the TRPA-managed Baileys coverage layer. When developing this indicator, data from the Lahanton Regional Water Quality Control Board TMDL project was also considered. The TMDL data included a data set for Erosion Potential that was derived using a different analysis than the Bailey's system and ranked erosion potential 1 -5, with 5 having the highest potential. It was thought that this might be a better data set for considering landscape resilience of erosion to disturbances. This data set was not used because we were unable to obtain the metadata for understanding the classification ranking and because there appeared to be missing data at the landscape level. When comparing Bailey's data to the TMDL data, there was little difference at the landscape level, with some more distinct differences at the fine scale.

For this indicator, resilience is ranked according to sensitivity to human disturbance, specifically creation of impervious coverage. Natural disturbances such as fire and erosion/floods follow the same ranking when considering the potential impacts to soils from extreme events (e.g. high severity fire and extreme precipitation events), however these impacts are temporal and recovery occurs relatively quickly (1-2 years post event), whereas creation of impervious coverage does not recover quickly and creates long lasting impacts on the landscape. Proper engineering and adequate Best Management Practices can mitigate some of these impacts, but not all.

Bailey's Land Capability Classification System for 1: 1a- steep slopes, 1b- poor natural drainage – SEZ, 1c- flora and fauna-SEZ.

Aquatic Organism Passage

The USFS aquatic biologist, Sarah Muskopf, warns not to look at this metric alone because Highway 89 is a major barrier to nearly all creeks, even those like General Creek that is considered relatively good habitat for native fish.

Floodplain Condition

This indicator is currently assessed as the areas within the FEMA 100 year floodplain, or TRPA defined Stream Environment Zone (SEZ, Bailey class 1) that contain impervious surfaces, including structures, roads, and trails. The impervious coverage layer was developed by Spatial Informatics Group derived from the August 2010 LiDAR collection and summer 2010 WorldView-2 imagery. The floodplain/SEZ and impervious areas were burned into the EcObject data so that it could be assessed with other metrics. There may be another meadow/riparian data source that could be used in addition or instead of the FEMA floodplain and TRPA SEZ.

Floodplain/SEZ EcObjects that do not contain impervious surfaces were assigned 0 indicating resilience. Floodplain/SEZ EcObjects that do contain impervious surfaces were assigned 1 indicating least resilient. The remainder of the analysis area (non-floodplain) was assigned a null value.

Bark Beetle Predators

The resilience of a forest system is influenced by factors other than forest structure and disturbance dynamics. Thompson et al. (2009) provide a well-developed synthesis of the essential role that biodiversity plays in laying the foundation for an ecosystem's resilience, and enhancing ecosystem stability at all scales. Many species and groups of species play important functional roles and, under changing environmental conditions, species with previously minimal functional responsibilities may take on increasingly important functional roles. The persistence of these functional groups is essential for ecosystem resilience. One functional group that plays a very important role in ecosystem resilience in the Lake Tahoe Basin is the cavity nesting bird guild that acts as primary predators on bark beetles and other potentially disruptive forest insects, including non-native insect pests.

Cavity nesting birds are important predators on bark beetles, which have contributed to recent conifer die-off events in the Lake Tahoe Basin and Sierra Nevada. These birds act as a biological control agent to moderate and reduce the effects of insect outbreaks and promote forest resilience to drought, fire, insects, and climate change. A synthesis of research on woodpecker predation on conifer bark beetle populations found that woodpeckers could regulate and stabilize bark beetle populations (Fayt et al., 2005). The effectiveness of control may depend on the population size of woodpeckers in the environment prior to infestation by bark beetles (Fayt et al., 2005; Jennings et al., 2013) indicating the importance of maintaining healthy populations of bark beetle predators. These birds may act nomadically to congregate in areas of high bark beetle density such that the total landscape population size of cavity nesters may be as important as the short-term, local numbers (Martin et al., 2006). Woodpeckers are particularly important agents of winter mortality in bark beetles resulting in a 45-98 percent decrease in winter beetle survival across several studies (Baldwin, 1960; Crockett and Hansley, 1978; McCambridge and Knight 1972) which may become increasingly important with increasing winter temperatures in the Tahoe basin that results in less temperature induced beetle die-off. Non-native, introduced species of bark beetles impact forested lands across the United States and woodpeckers can be a substantial source of mortality on species such as the Emerald Ash Borer (Jennings et al., 2013). The possible role of forest birds in biological control of beetles is not limited to woodpeckers as the suite of forest cavity nesters may moderate the onset, distribution, duration, or intensity of outbreaks by delaying the initiation of an outbreak and/or increasing the trajectory of decline after the peak of the outbreak (Martin et al., 2006). This moderation could result in a substantial decline in total tree mortality during a beetle outbreak. These birds are also important for biological control of other insect pests such as the white satin moth, which can decimate aspen and cottonwood stands in the absence of natural predators (http://forestry.nv.gov/wp-content/uploads/2012/07/white-satin-moth.pdf).

The benefits of using the functional guild approach is that species within the guild respond differently to fire, other disturbances, and forest condition (Saab et al., 2007). A well-represented suite of these species across the landscape is indicative of habitat drivers important for these species such as aspen or other hardwoods, large trees, large snags, burned areas, undisturbed old forest, and general heterogeneity. These habitat components are also important for forest resilience, highlighting the value of this guild as an indicator. It is important to understand that bark beetles and other forest insects are important components of a resilient forest in terms of promoting heterogeneity, gap development, genetic selection, tree species composition, and food web dynamics; so presence of forest insects, and association of bark beetle predators with these insects, should not be interpreted as indicative of a non-resilient forest state. It is the large outbreaks driven by drought and climate change, which have the capacity to affect resilience. These large scale and extreme disturbance events (or disturbance pressures that are happening too frequently) also result in steep declines in bark beetle predators as vast areas of dead trees eventually rot and fall to the ground, leaving a lack of potential nest trees (Newton 1998). In this way, delayed bark beetle predator occupancy decline would be an indicator of large-scale tree die-off events.

The US Forest Service developed the Multiple Species Inventory and Monitoring (MSIM) protocol based on presence, absence data for a broad spectrum of species at systematic sample points. The ability of this protocol to detect population change across a broad spectrum of vertebrate species was verified for the Lake Tahoe Basin (Manley et al., 2005) and it is well suited to meet the monitoring needs of land management agencies in assessing change detection in biodiversity, which is essential for forest resilience. Disturbance from human activity was, surprisingly, the most important factor influencing species richness in the Lake Tahoe Basin (Schlesinger et al., 2008) providing one example of how this approach will be valuable in assessing other unanticipated changes in the entire vertebrate community, as well as different functional groups of species, including among bark beetle predators.

White and Manley (2013) developed a field data based evaluation tool, specific to the Lake Tahoe Basin, which provides wildlife habitat occurrence models for project and landscape evaluations (https://www.fs.fed.us/psw/partnerships/tahoescience/documents/p050_FinalReportWildlifeHabitat.p df). These models use data from two primary datasets: 1) the Multi-Species Inventory and Monitoring (MSIM) data, collected at 100 sites on NFS lands throughout the basin from 2002-2005; 2) the Lake Tahoe Urban Biodiversity Study (LTUB) data collected at 100 sites across multiple land ownerships at lower elevations (<7500 ft) in the basin from 2003-2005. Together they represent the full spectrum of the primary environmental conditions occurring in the basin, meaning locations around the lake and sites from lake level to near the crest.

Methods:
Fourteen probability-of-occurrence rasters were summed (see table below for list of the cavity nesting species included). This produced a raster with a range of 2.258 to 7.633. This raster was then divided by 14 for an average probability of occurrence value between 0.180 and 0.491. A 5-class (Jenks natural breaks) was then identified to relativize the probability (see table below). The average raster was then reclassified based on the natural breaks and assigned a resilience rank. Reclassified raster was resampled to 5 meters, zonal statistics was used to identify the majority pixel under each EcObject.

Table A-12 Cavity nesting species included in analysis.

		PC_nester	SC_nester	
BBWO	Black-backed woodpecker	√		
HAWO	Hairy woodpecker	√		
NOFL	Northern flicker	√		
PIWO	Pileated woodpecker	√		
RBSA	red-breasted sapsucker	√		
WHWO	White-headed woodpecker	√		
WISA	Williamson's sapsucker	√		
BRCR	Brown creeper		√	
HOWR	House wren		√	
MOBL	Mountain bluebird		√	No suitability raster
MOCH	Mountain chickadee		√	
PYNU	Pygmy nuthatch		√	
RBNU	red-breasted nuthatch		√	
TRES	Tree swallow		√	No suitability raster
VGSW	Violet-green swallow		√	No suitability raster
WBNU	White-breasted nuthatch		√	
WEBL	Western bluebird		√	No suitability raster
WIWR	Winter wren		√	

Based on an analysis of functional strength in the cavity nesting bird community quantified between a range of 0-1 with habitat represented by a 1 as providing the probability of suitable habitat as low (and therefore less resilient) and a 0 representing the probability of suitable habitat as high (and therefore more resilient) in the analysis area to support breeding territories for all members of the functional group.

Table A-13 Resilience rank by probability of occurrence.

Resilience Rank	Probability of Occurrence
0	0.383671916 - 0.49116981

0.25	0.354354308 - 0.383671916
0.5	0.317707299 - 0.354354308
0.75	0.270066186 - 0.317707299
1	0.17967023 - 0.270066186

Limitations of this indicator: This dataset is from 2007 (and prior).

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Native Fish Diversity

Data for this indicator come from the LTBMU Basin-wide native non-game fish assessment 2007-2014 comprehensive report (USDA 2016). Data were collected at 26 streams in the Lake Tahoe Basin, including all the major streams on the west shore from 2007 to 2014. Streams were divided into 100 meter segments; streams were electro-shocked and the species were counted and released. Data collected were used to measure presence, distribution, and relative abundance.

Literature Used

USDA. December 2016. Basin-wide Native non-game fish assessment, 2007-2014 comprehensive report. Written by Erin Miller, Reviewed and approved by Sarah Muskopf, Lake Tahoe Basin Management Unit, US Forest Service.

Indicators with Proportional Resilience Values

Seral Stage

The resilience scale ranging from 0 to 1 with 0 having the greatest resilience. This scaling was used to provide for scaling up and combining multiple indicators to evaluate resilience. Items that are outside of acceptable resilient conditions and are under-represented are assigned a resilience rank of 0.5. Although these stands could be considered resilient because they are not over-represented, because they are underrepresented they have a risk of being lost from the landscape. Items that are outside of acceptable resilient conditions and are over-represented are assigned a resilience rank of 1. All other conditions with data will be given a resilience rank of 0. For items with no data, 999 was used.

For this indicator we used two data sources: desired conditions from the LTBMU Forest Plan (USDA 2016) and the Yuba River Historic Range of Variation analysis, which was summarized by Becky Estes in the draft South Fork American River Desired Conditions. Due to differences in seral classifications, cut-offs incorporated the larger end of the upper and lower range to provide a more liberal range. The original tables can be found below.

Table A-14 LTBMU Forest Plan (2016). Landscape Scale Desired Conditions for Major Forest Vegetation Types Showing Desired Average Percent of Vegetation Type.

Vegetation Description	Approx. Percent of Area 1935	Approx. Percent of Area 2003	Early-Seral	Mid-Seral, Closed Canopy	Mid-Seral, Open Canopy	Late-Seral, Open Canopy	Late-Seral, Closed Canopy
White fir Mixed conifer	10	21	10-20	5-15	10-15	30-40	20-30
Jeffrey Pine	37	19	5-15	5-10	25-30	45-50	5-10
Red Fir	15	18	10-20	20-30	5-15	15-25	25-35
Notes: • 1935 percent of area from Forest Service 1935 Vegetation Type Map (Wieslander); these numbers represent an interim basin-wide desired condition. • 2003 percent of area from Lake Tahoe Basin Existing Vegetation Map, Version 4.1, updated for the 2007 Angora Fire.							

• This table is derived from Historic Reference Condition modeling for major LTB forest types, developed from non-linear forest stand dynamics (state and transition) modeling, using disturbance regimes from pre-Euro-American settlement period. Climate inputs from 20th century. Values cannot be reliably applied to landscape units less than about 10,000 acres in area (Safford and Schmidt 2007). • Early, mid, and late seral stages represent stand quadratic mean diameters of 0-5”, 5-25”, and >25” dbh respectively. • For white fir, and the red fir types, an “open” canopy has less than 50 percent closure while a closed canopy has closure greater than 50 percent; for Jeffrey pine, the open-closed cutoff is 40%. For detailed seral stage definitions, see Historic Reference Condition Mapping, Safford and Schmidt 2007.

Table A-15 Yuba River HRV: Percentages (median and range (5-95% percentiles) of developmental stage (early, mid or late) in canopy cover class (open, moderate, or closed) for the corresponding cover type.

Seral Stage[1]	Ponderosa pine/Jeffrey pine	Dry Sierra mixed conifer	Mesic Sierra mixed conifer	Mixed Evergreen	Red fir
ED	10 (7-12)	10 (7-12)	7 (5-14)	7 (3-13)	8 (3–20)
MDO	9 (8-14)	9 (8-14)	11 (4–10)	1 (0-1)	1 (0 -2)
MDM	3 (2-5)	3 (2-5)	7 (5–10)	4 (2-10)	1 (0 -2)
MDC	1 (0-2)	1 (0-2)	6 (7–15)	1 (0-3)	19 (12-29)
LDO	38 (29–50)	38 (29–50)	34 (8–23)	6 (3-13)	4 (2 7)
LDM	26 (20–31)	26 (20–31)	18 (15–24)	11 (8 – 15)	7 (5–8)
LDC	13 (7–21)	13 (7–21)	14 (21–45)	68 (57-79)	60 (47–70)

[1] Seral stage refers to overstory tree DBH (inches) and overstory tree canopy from above. Early development (ED): ≥5" & <25%; Mid development open (MDO): 5-19.9” & <40%; Mid development moderate (MDO): 5-19.9” & 40-70%; Mid development closed (MDC): 5-19.9” & >70%; Late development open (LDO): >20” & <40%; Late development moderate (LDM): >20% & 40-70%; Late development closed (LDC): >20” & >70%.

Figure A-4 Spatial data indicating where the various seral stages exist in the LTW project area.

Vertical Heterogeneity

The resilience scale ranging from 0 to 1 with 0 having the greatest resilience. This scaling was used to provide for scaling up and combining multiple indicators to evaluate resilience. Green highlighted items indicate items that are outside of desired conditions and are under-represented and will be given resilience rank of 0.5 (while these stands would be resilient because they are not over-represented, if lost they could quickly become not resilient and therefore mid-range scale). Yellow highlighted items indicate items that are outside of desired conditions and are over-represented and will be given resilience rank of 1. All other conditions with data will be given a resilience rank of <null> for no data. Resilience is proportional to how far removed from desired conditions the landscape indicator is.

Resilient condition: *The landscape is heterogeneous which will increase landscape resilience*. Note this indicator is appropriate at the landscape scale and at the landscape management unit (LMU) scale.

Table A-16 Percentage of vertical heterogeneity resilient conditions and comparison with current LTW conditions. Green highlighted items indicate items that are outside of resilient conditions and are under-represented and will be given resilience rank of 0.5. Yellow highlighted items indicate items that are outside of resilient conditions and are over-represented and will be given resilience rank of 1. All other conditions will be given a resilience rank of 0.

Strata Distribution Class	DC Rank	LTW Rank	Lower % Range	Upper % Range	LTW % of forested landscape	Acres
Top Loaded	1	2	49.22	73.83	24%	9,228.82
Mid Loaded	2	3	13.52	20.28	22%	8,473.54
Bimodal - Codominance	3	5	11.39	17.08	6%	2,485.57
Continuous	4	4	3.32	4.97	17%	6,438.29
Bottom Loaded	5	1	2.05	3.07	28%	10,716.95
Bimodal - Subdominance	6	6	0.51	0.76	3%	1,104.76
TOTAL*					**100%**	**38,447.95**
*N/A covers 35% of the total LTW Area (20,427 acres of the 58,875 acres). This was excluded in the table.						

Table A-17 Vertical heterogeneity resilient condition for forested conditions. Numbers are the rank with one being the greatest proportion of that individual class 7 being the lowest proportion of the class by LMU. Percentage of LMU is provided based on the Illiloutte reference sites ±20%. Desired conditions should focus on the ranks with range as a guidance due to single value and lack of data supporting range of values.

Description	Strata Distribution Class	Rank	Lower % Range	Upper % Range
Single old	Top Loaded	1	49.22	73.83
Single mid	Mid Loaded	2	13.52	20.28
Codominant - attached	Bimodal - Codominance	3	11.39	17.08
Tri-dominant – 3 equal classes	Continuous	4	3.32	4.97
Single young*	Bottom Loaded	5	2.05	3.07
Codominant - detached	Bimodal - Subdominance	6	0.51	0.76
* Early seral stands.				

Spatial patterns are important resilience indicators because they influence disturbance behavior, regeneration, snow retention, and habitat quality. While these are important indicators there is limited reference information identifying resilient conditions. The Illilouette basin reference LiDar dataset was the only dataset that was used in developing the desired conditions. If additional references are relevant to vertical heterogeneity it would be beneficial to expand range of desired conditions.

The Illilouette basin had a LiDar flight and EcObjects were derived in an identical workflow to the LTB. This area has had an active lower-severity fire regime and therefore was considered a suitable reference site since fire is the keystone process in maintaining resilient conditions in this landscape. Reference sites for Lake Tahoe West specifically were selected from the Illilouette acquisition based on: if the cell was Sierra Nevada mixed conifer forest, at least 2 fires in the last 60 years, at least 1 fire in the last 30 years, at least 1 moderate severity fire, no high severity fire, was a patch ≥250 acres, and had similar water balance classes to LTW. These data were then used to summarize both horizontal heterogeneity and vertical heterogeneity to directly compare the LTW dataset with reference dataset.

EcObject field strata distribution classifies vertical structure of polygons with clumps of trees (where spatial variable classification is clump, scattered clump, or dense clump) based on the four canopy cover slices – 2 meters to 8 meters, 8 meters to 16 meters, 16 meters to 32 meters, and 32 meters and above and their relative proportion of their combined cover. EcObject classification of strata distribution is as follows:

- N/A: open, stand initiation, sparse, individual, road, river, lake, development
- Bottom loaded: dominant canopy cover is between 2-8 meters (either multi-strata or single strata)
- Mid-loaded: dominant canopy is at the mid-range of 8-16 (single or multi-strata) or 16-32 meters (multi strata)
- Top-loaded: dominant canopy cover is at the top of strata 16-32 meters or greater than 32 (single or multi strata)
- Bimodal-codominance: co-dominance of two canopies that are similar in height and are within 5% of each other: 8-16 and 16-32, or 16-32 and 32 and greater.
- Bimodal-subdominance: co-dominate strata that are detached in height and are within 5% of each other: 2-8 and 16-32, or 8-16 and 32 and greater, or 2-8 and 32 and greater
- Continuous: at least 3 strata co-dominant with equal proportions of canopy cover

We evaluated vertical heterogeneity by LMU, but did not move this forward into the assessment because the relative abundance of each LMU is similar and therefore it did not add much to the resilience assessment (see table below).

Table A-18 Resilient condition vertical heterogeneity by landscape management unit (LMU). Numbers are the ranks, with one being the greatest proportion of that individual class by LMU and 7 being the lowest proportion of the class by LMU. Percentage of LMU is provided based on the Illiloutte reference sites ±20%. Desired conditions should focus on the ranks with range as a guidance due to single value and lack of data supporting range of values.

Strata Distribution Class	Ridge Rank	Ridge % Range	Canyon Rank	Canyon % Range	NE Slope Rank	NE Slope % Range	SW Slope Rank	SW Slope % Range
Top Loaded	1	35.72-53.58	1	47.73-71.59	1	49.23-73.84	1	53.74-80.61
Mid Loaded	2	16.34-24.51	2	13.85-20.77	2	13.80-20.70	2	12.37-18.55
Continuous	3	14.81-22.21	3	13.18-19.76	3	12.15-18.22	3	10.03-15.05
Bimodal - Codominance	4	6.75-10.13	4	3.52-5.28	5	1.60-2.40	4	1.74-2.61
Bottom Loaded	5	5.58-8.36	5	1.57-2.35	4	2.64-3.96	5	1.38-2.07
Bimodal - Subdominance	6	0.80 - 1.21	6	0.16-0.24	6	0.59-0.88	6	0.75-1.12

Patch size was evaluated, however due to the nature of how EcObjects were developed these do not make sense. We tried both vertical, horizontal, and conglomerating up with seral class and species.

However, all of the patches were themselves heterogeneous and were not homogenous regardless of size and therefore we dropped this.

Table A-19 Desired condition minimum and maximum patch size (acres) and resilience rating based on EcObject ranges for the Illilouette reference sites within each vertical heterogeneity class.

Description	Strata Distribution Class	Min patch size (Acres)	Max patch size (Acres)	VH Resilient (0)	VH Not-resilient (1)
Homogenous old	Top Loaded	0.01	18.11	≤18	>18
Homogenous mid	Mid Loaded	0.01	5.06	≤5	>5
Codominant – attached	Bimodal - Codominance	0.03	15.14	≤15	>15
Vertically Heterogeneous	Continuous	0.01	15.97	≤16	>16
Homogenous young	Bottom Loaded	0.01	1.34	≤2	>2
Codominant - detached	Bimodal - Subdominance	0.05	2.4	≤3	>3

Figure A-5 Spatial data for the location of the various vertical heterogeneity classes in the LTW project area.

Literature Used

Clyatt, K. A., J. S. Crotteau, M. S. Schaedel, H. L. Wiggins, H. Kelley, D. J. Churchill, and A. J. Larson. 2016. Historical spatial patterns and contemporary tree mortality in dry mixed-conifer forests. Forest Ecology and Management **361**:23-37.

Lydersen, J. M., M. P. North, E. E. Knapp, and B. M. Collins. 2013. Quantifying spatial patterns of tree groups and gaps in mixed-conifer forests: Reference conditions and long-term changes following fire suppression and logging. Forest Ecology and Management **304**:370-382.

Thorne, J. H., R. Kelsey, J. Honig, and B. Morgan. 2006. The development of 70-year-old Wieslander vegetation type maps and an assessment of landscape change in the central Sierra Nevada.

Van de Water, K. M., and H. D. Safford. 2011. A summary of fire frequency estimates for California vegetation before Euro-American settlement. Fire Ecology **7**:26-58.

Horizontal Heterogeneity

The resilience scale ranging from 0 to 1 with 0 having the greatest resilience. This scaling was used to provide for scaling up and combining multiple indicators to evaluate resilience. Green highlighted items indicate items that are outside of desired conditions and are under-represented and will be given resilience rank of 0.5 (while these stands would be resilient because they are not over-represented, if lost they could quickly become not resilient and therefore mid-range scale). Yellow highlighted items indicate items that are outside of desired conditions and are over-represented and will be given resilience rank of 1. All other conditions with data will be given a resilience rank of 0. 999 was used for no data.

Table A-20 Lower and Upper resilient condition ranges and comparison with horizontal heterogeneity found within the LTW project area.

Spatial Variation Class (terminology used in Lydersen)	Lower % Range	Upper % Range	LTW % of forested landscape
Individuals/Sparse[1]	1	7	1%
Open (Gaps)	20	27	8%
Stand initiation[2]	17		18%
Scattered clumps (2-4 trees, low cover)	13	36	34%
Clump (medium 5-9 trees)	11	15	28%
Dense clump (large, >10 trees)[3]	0.5	66	6%
All clumps[4]	48		68%

[1] Note sparse class was lumped into individuals, however based on how data was processed this could have been lumped into scattered clumps as well, lowering the range of scattered clumps to 7%.
[2] Stand initiation was likely considered a "gap" under Lyderson, however this class in EcObject indicates that the gap could transfer to forested stand while other gaps may not and therefore this was kept separate. This class would be considered early seral.
[3] Note this is a very large range. 0.5 is from Illilouette and 66% is from Lyderson
[4] This was calculated by summarizing all clumps from the Illilouette data

Patch size was evaluated however due to the nature of how EcObjects were developed these do not make sense. We tried both vertical, horizontal, and conglomerating up with seral class and species. However, all of the patches were themselves heterogeneous and were not homogenous regardless of size and therefore we dropped this.

Table A-21 Desired condition minimum and maximum patch size (acres) based on EcObject ranges for the Illilouette reference sites (HH) within each spatial variation class.

Spatial Variation Class	Min patch size (Acres)	Max patch size (Acres)	HH Resilient (0)	HH Not-resilient (1)
Clump	0.02	18.11	≤18	>18
Dense Clump	0.14	4.97	≤5	>5
Individual	0.01	0.22	≤1	>1
Open*	0.1	46.11	≤46	>46
Scattered Clump	0.01	16.34	≤16	>16
Sparse	0.01	1.65	≤2	>2
Stand Initiation	0.01	19.94	≤20	>20

Table A-22 Desired Condition (DC) percentage ranks and Resilience Rank (0-1) or the Illilouette reference sites (HH) within each spatial variation class.

Spatial Variation	DC Ridge Rank	HH Resilience - Ridge	DC Canyon Rank	HH Resilience - Canyon	DC NE Slope Rank	HH Resilience – NE Slope	DC SW Slope Rank	HH Resilience – SW Slope
Clump	5	1	3	1	5	1	4	1
Dense Clump	7	0	7	1	7	1	7	0
Individual	6	0	6	0	6	0	6	0
Open	1	0.5	2	0.5	3	0.5	2	0.5
Scattered Clump	3	1	1	0	1	0	1	0
Sparse	4	0	5	0	4	0	5	0
Stand Initiation	2	0	4	0	2	0	3	0

Note we may want to remove open from resilience because this can be driven by non-forested conditions where Illilouette may not be representative – evaluate data once produced.

EcObject field spatial variation uses number of trees, trees per acre, and percent canopy cover above 2 meters. EcObject classification of spatial variation is as follows:

- Open: no trees sometimes with few seedlings or saplings.
- Stand initiation: multiple trees with canopy cover less than 10%
- Sparse: multiple trees with canopy cover between 10-29%
- Individual: one tree that can be any size: pole sapling, young, old, or mature
- Scattered clump: multiple trees with canopy cover 30-49%
- Clump: multiple trees with canopy cover 50-69%
- Dense clump: multiple trees with canopy cover 70+%

Figure A-6 Spatial data used to indicate where the various horizontal heterogeneity classes exist in the LTW project area.

Literature Used

Clyatt, K. A., J. S. Crotteau, M. S. Schaedel, H. L. Wiggins, H. Kelley, D. J. Churchill, and A. J. Larson. 2016. Historical spatial patterns and contemporary tree mortality in dry mixed-conifer forests. Forest Ecology and Management **361**:23-37.

Lydersen, J. M., M. P. North, E. E. Knapp, and B. M. Collins. 2013. Quantifying spatial patterns of tree groups and gaps in mixed-conifer forests: Reference conditions and long-term changes following fire suppression and logging. Forest Ecology and Management **304**:370-382.

Thorne, J. H., R. Kelsey, J. Honig, and B. Morgan. 2006. The development of 70-year-old Wieslander vegetation type maps and an assessment of landscape change in the central Sierra Nevada.

Van de Water, K. M., and H. D. Safford. 2011. A summary of fire frequency estimates for California vegetation before Euro-American settlement. Fire Ecology **7**:26-58.

Visual Overlay Indicators

Treatment Type

We initially ranked resilience based on the following:

- Fire treated (with some form of fire, understory, wild, etc – but not piles) = 0
    - If a site had multiple burn treatments it would be considered more resilient than a single burn; however, currently we do not have this situation.
- Thinning treated (thinning or pile burning only) = 0.5
- Not treated (planned treatments will fall into this as well) = 1

However, after ranking this indicator we evaluated if it added anything new during comparison of roll up indicators (see table below) and it did not. Therefore, we decided to use treated as an overlay only identifying areas that have been thinned or burned.

Table A-23 Percentage of land in each resilience class compared between treatment and condition class resiliency. Note how the greatest proportion of the land is in treatment RR 1 and CC RR 1 and therefore, these two indicators combined are not providing much additional information.

		Mean Condition Class		
		0	**0.5**	**1**
Treatment	**0**	0.00	0.02	0.25
	0.5	0.08	0.26	12.39
	1	2.71	18.33	59.52
	<blank>	0.14	0.62	5.68

Vegetation Type

This indicator will only be presented spatially as this is what is where, but will not be presented spatially as far as resilience. Mixed conifer forest is the only vegetation type on the landscape that is outside of the resilient condition (Table A-15). While this is important information to know, we did not feel that coding all mixed conifer as over-represented would provide much information to the assessment, especially if the assessment is conducted for individual vegetation types.

Table A-24 Desired condition percentage of the landscape within each general vegetation type and comparison with current LTW conditions. Highlighted items indicate items that are outside of resilient conditions.

Veg	**Lower % Range**	**Upper % Range**	**LTW % of forested landscape**
Aspen	0.002	1	0%
Herbaceous (grassland, meadow, etc.)	1	6	0%
Mixed Conifer	8	28	57%
None (barren, lake, etc.)	4	7	3%
Red Fir	12	72	19%
Riparian	0.08	6	0%
Shrub	1	14	4%
Subalpine Forest	0.1	11	6%
Yellow Pine	7	37	7%

Methods: Two spatial datasets (Landfire and VTM) suggestive of the historical range of variability were used to bound percentage of each vegetation types. A ten percent buffer was then placed on the upper and lower range. These values were then cross referenced with the LTBMU FS Plan interim desired conditions (Table 1. Landscape Scale Desired Conditions for Major Forest Vegetation Types Showing Desired Average Percent of Vegetation Type). Yellow Pine upper range was increased from 34 to 37% from FS Plan DC, all other values fell within the range developed with the spatial dataset methodology presented below.

LANDFIRE biophysical settings (BpS) data (http://www.landfire.gov/NationalProductDescriptions20.php) depicts reference condition of vegetation on the landscape based on approximation of historic disturbance regimes and contemporary biophysical environment. These data can be used to inform restoration targets for species composition and seral-structural class proportions. The actual time period for this data set is a composite of both the historical context provided by the fire regime and vegetation dynamics models and the more recent field and geospatial data used to create it. The BpS types were lumped into PFTs (pre-settlement fire regime vegetation types) following (Van de Water and Safford 2011) and then into general vegetation types for this landscape (Appendix Table 1).

Wieslander vegetation type map (VTM) project was a vegetation mapping effort from the 1930's. This dataset represents an excellent historical record to assess past vegetation, which can be used to infer the natural range of variability and resilience. Digital maps were produced for a portion of the Sierra Nevada and were classified based on California wildlife habitat type relationship system (C-WHR) (Thorne et al. 2006). These types were lumped into the same general vegetation types that the BpS data were lumped into and were used to assess vegetation from the 1930's (Appendix Table 2).

Table A-25 Percentages of general vegetation type based on BpS and VTM, resilient condition ranges based on two datasets, and final resilient condition based on rounding with ±10%.

Veg	BpS %	VTM %	Lower Range	Upper Range	Less 10%	Plus 10%
Aspen	0.00	0.01	0.00	0.01	0.002	1
Herbaceous	5.76	0.99	0.99	5.76	1	6
Mixed Conifer	9.20	25.14	9.20	25.14	8	28
None	4.99	6.81	4.99	6.81	4	7
Red Fir	65.07	12.99	12.99	65.07	12	72
Riparian	5.23	0.08	0.08	5.23	0.08	6
Shrub	1.31	12.81	1.31	12.81	1	14
Subalpine Forest	0.16	9.84	0.16	9.84	0.1	11
Yellow Pine	8.29	31.32	8.29	31.32	7	34

Limitations from range of resilient conditions presented: The range of data presented is assumed to be resilient under historic climate regimes. This is a good starting point to target future resilience, however incorporation of future climate is important. Climatic water deficit could be used in combination with restoration plans to identify where a vegetation type more resilient under hotter conditions may succeed. For example an area may be more suitable to be managed as a mixed conifer hardwood compared to a moist mixed conifer.

Table A-26 BpS – PFT – General vegetation type crosswalk.

General	PFTs	BpS
Aspen	Aspen	Rocky Mountain Aspen Forest and Woodland
Herbaceous	None-herbaceous	Inter-Mountain Basins Sparsely Vegetated Systems
		North Pacific Montane Grassland
Mixed Conifer	Dry mixed conifer	Mediterranean California Dry-Mesic Mixed Conifer Forest and Woodland
	Lodgepole pine	Sierra Nevada Subalpine Lodgepole Pine Forest and Woodland - Dry
		Sierra Nevada Subalpine Lodgepole Pine Forest and Woodland - Wet
	Moist mixed conifer	Mediterranean California Mesic Mixed Conifer Forest and Woodland
	Pinyon juniper	Columbia Plateau Western Juniper Woodland and Savanna
		Great Basin Pinyon-Juniper Woodland
None	None-Barren	Barren-Rock/Sand/Clay
		Mediterranean California Alpine Fell-Field
		Perennial Ice/Snow
	None-Water	Open Water
Red Fir	Red Fir	Mediterranean California Red Fir Forest - Cascades
		Mediterranean California Red Fir Forest - Southern Sierra
Riparian	None-Riparian	California Montane Riparian Systems
		Inter-Mountain Basins Montane Riparian Systems
Shrub	Big sagebrush	Inter-Mountain Basins Big Sagebrush Shrubland
		Inter-Mountain Basins Montane Sagebrush Steppe
	Chaparral/serotinous conifers	Mediterranean California Mesic Serpentine Woodland and Chaparral
	Desert mixed shrub	Inter-Mountain Basins Greasewood Flat
	Montane chaparral	California Montane Woodland and Chaparral
	Oak woodland	Mediterranean California Mixed Oak Woodland
Subalpine Forest	Subalpine forest	Mediterranean California Subalpine Woodland
		Northern California Mesic Subalpine Woodland
		Sierra Nevada Alpine Dwarf-Shrubland
Yellow Pine	Yellow Pine	California Montane Jeffrey Pine(-Ponderosa Pine) Woodland
		Mediterranean California Lower Montane Black Oak-Conifer Forest and Woodland

Table A-27 WHR vegetation type from VTM data – General vegetation type crosswalk.

General	WHR
Aspen	Aspen - ASP

General	WHR
Herbaceous	Annual Grassland - AGS
	Wet Meadow - WTM
Mixed Conifer	Lodgepole Pine - LPN
	Montane Hardwood - MHW
	Montane Hardwood-Conifer - MHC
	Sierran Mixed Conifer- SMC
	White Fir - WFR
None	Barren - BAR
	Lacustrine – LAC
	Unknown
	Urban – URB
Red Fir	Red Fir - RFR
Riparian	Montane Riparian - MRI
Shrub	Bitterbrush - BBR
	Desert Scrub - DSC
	Montane Chaparral - MCP
	Sagebrush - SGB
Subalpine	Subalpine Conifer - SCN
Yellow Pine	Eastside Pine - EPN
	Jeffrey Pine - JPN
	Ponderosa Pine - PPN

Composite Indicators

Each indicator was correlated with every other indicator to determine if individual indicators were correlated using Kendall pairwise comparison. Kendall correlation was used because it is a non-parametric test used to measure the ordinal associate between two measured quantities and works on non-continuous data. This allowed us to evaluate to see if any indicators were providing the same information, in which case we would not want to average the data. There was only one pair of indicators with a correlation >0.5 (see figure and table below) which was meadow refugia and native fish diversity (0.55). We kept both indicators in the analysis because these target different systems and we felt like the information was additive rather than redundant.

After composite indicators were averaged, the correlation was evaluated between composite indicators to identify where composites may be providing similar information. Pearson's R correlation was used for this analysis because it is a measure of the linear correlation between two variables *X* and *Y* based on continuous data.

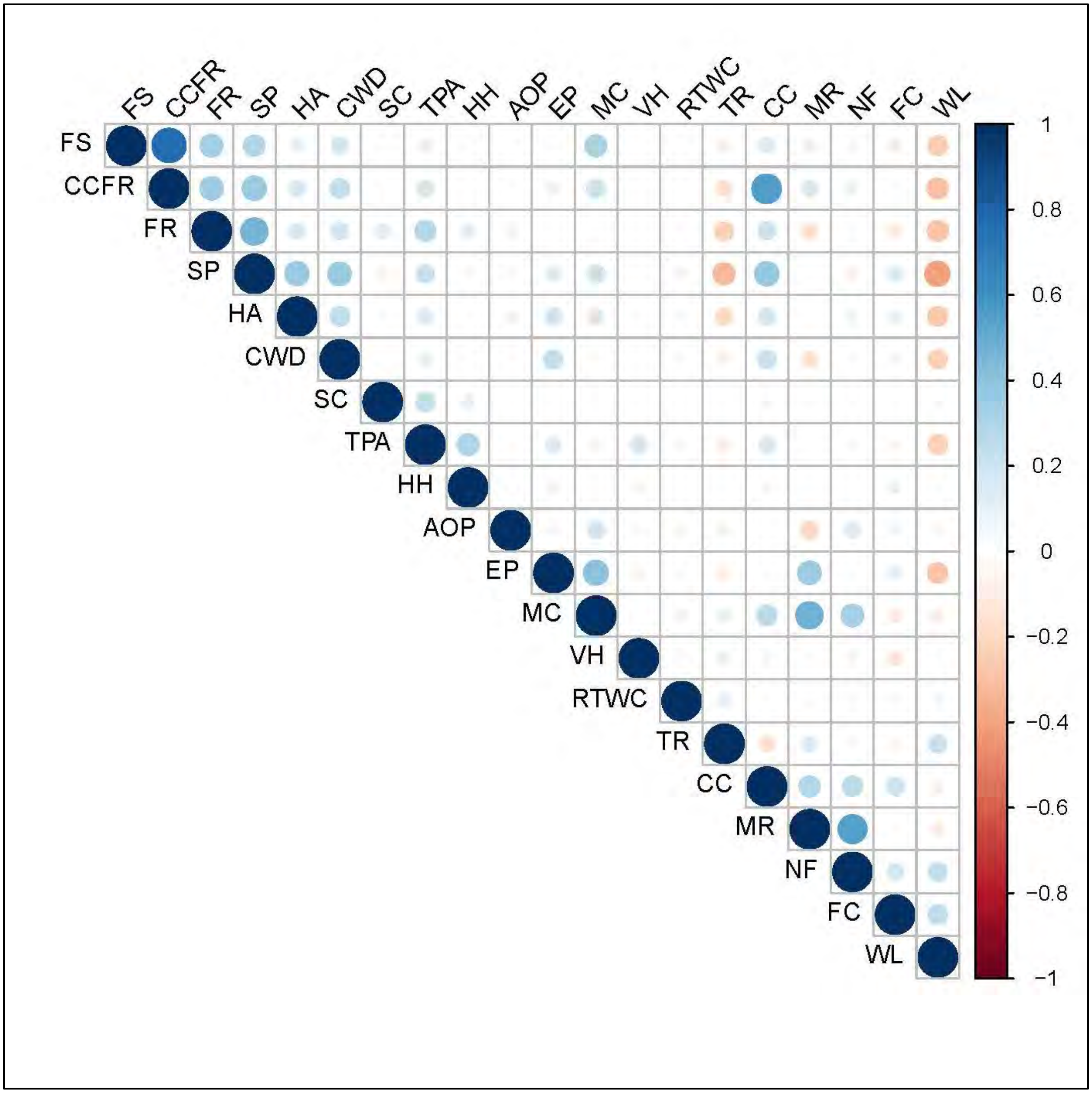


Figure A-7 Kendall correlation plot for individual indicators. Larger circles indicate greater correlation; blue circles indicate positive correlation and red circles indicate negative correlation.

Table A-28 Correlation matrix for individual indicators based on Kendall correlation. Grey cells indicate correlations >0.5.

	FS	CC	FR	SC	VH	TPA	RTWC	HA	FC	WL	SP	CWD	TR	EP	HH	MC	MR	NF
FS	1.00																	
CC	0.15	1.00																
FR	0.33	0.20	1.00															
SC	-0.02	-0.07	0.13	1.00														
VH	-0.01	0.05	0.01	0.02	1.00													
TPA	0.10	0.16	0.27	0.24	0.16	1.00												
RTWC	0.00	-0.02	-0.03	0.02	-0.03	0.04	1.00											
HA	0.10	0.18	0.16	-0.03	-0.04	0.14	-0.04	1.00										
FC	-0.09	0.20	-0.11	-0.02	-0.12	-0.07	-0.05	0.10	1.00									
WL	-0.24	-0.07	-0.28	0.05	0.04	-0.24	0.06	-0.26	0.24	1.00								
SP	0.29	0.37	0.46	-0.06	0.01	0.21	-0.07	0.37	0.15	-0.41	1.00							
CWD	0.17	0.21	0.19	-0.02	-0.01	0.10	-0.04	0.24	0.05	-0.23	0.36	1.00						
TR	-0.09	-0.15	-0.23	-0.01	0.09	-0.11	0.10	-0.19	-0.05	0.21	-0.31	-0.09	1.00					
EP	0.03	0.04	0.01	-0.02	-0.07	0.15	0.04	0.18	0.11	-0.27	0.13	0.23	-0.08	1.00				
HH	0.03	-0.05	0.12	0.11	-0.06	0.30	0.01	0.03	0.08	-0.04	0.04	0.01	0.03	0.07	1.00			
MC	0.31	0.26	0.03	-0.01	-0.02	0.06	0.08	0.15	-0.10	-0.10	0.21	-0.05	0.10	0.40	-0.03	1.00		
MR	0.09	0.29	-0.16	0.04	-0.03	-0.01	0.05	0.01	-0.02	-0.11	-0.01	-0.15	0.15	0.35	0.01	0.47	1.00	
NF	0.04	0.25	-0.04	-0.02	-0.06	-0.04	-0.05	0.07	0.17	0.22	-0.08	-0.02	-0.03	-0.01	-0.01	0.32	0.55	1.00
AOP	0.00	0.01	0.06	-0.03	-0.05	0.01	-0.05	0.09	0.07	-0.06	0.06	0.03	-0.07	0.07	0.01	0.18	-0.19	0.15

R Code for correlation analysis:

```
library(reshape)
library(corrplot)
library(PerformanceAnalytics)
#data structure is headers on columns, values in rows, no row labels, values are
#0, 0.25, .5, .75, 1; blanks are included in data
df <- read.csv("RR.csv")
RR_cor <- cor(df, use="pairwise.complete.obs", method="pearson") #for composite indicators
RR_corK <- cor(df, use="pairwise.complete.obs", method="kendall") #for individual indicators

#write correlation plot to pdf - library: corrplot
pdf("RR_corrplot.pdf")
corrplot(RR_corK, type="upper", order="hclust", tl.col="black",tl.srt=45)
dev.off()

#write correlation plot to pdf - library: PerformanceAnalytics
pdf("RR_corrchart.pdf")
chart.Correlation(RR_cork, use = "pairwise.complete.obs")
dev.off()

# Produce ordered list of most correlated values
require(reshape)
RR_corK
k[upper.tri(RR_corK, diag=TRUE)] <- NA
m = melt(RR_cor)
m <- m[order(- abs(m$value)), ]
RR_cork_list <- na.omit(m)
write.csv(RR_cork_list, file="RR_cork_list.csv")
```

Appendix B - Individual and Composite Indicator Resilience Maps

Contents

Individual Indicators

In total, the IADT evaluated 21 indicators, 19 of which have data available to make a resilience assessment. Two additional indicators (treatments and vegetation types) are considered “overlays”, meaning that do not in and of themselves tell us whether or not the landscape is resilient where those conditions exist. Figures for these Overlay Indicators are in the Appendix A.

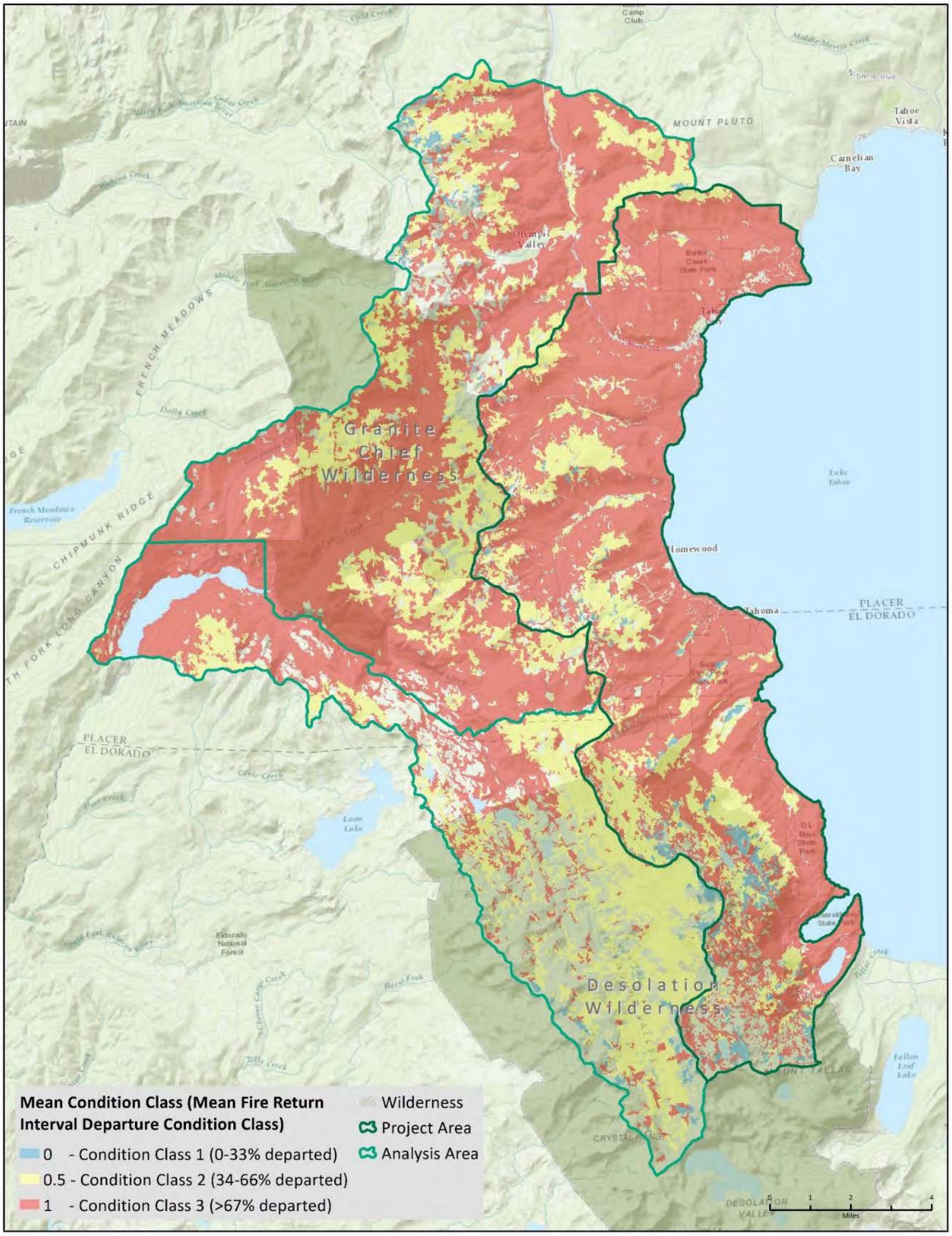
Indicators were either evaluated using Ecological Object Based Vegetation Mapping (EcObject) or were appended to the EcObject dataset. To determine the current state of resilience and the desired resilient condition for the 19 indicators, current data were compared to historic and/or contemporary reference conditions for that indicator. From this comparison, the IADT assigned the indicator a quantitative value for resilience on a scale from 0 to 1, with 0 being the most resilient, and 1 being the least. For those data for which a comparison was not applicable (e.g., Human Access), the IADT selected thresholds (e.g., ½ mile from trail, ¼ - ½ mile from trail) for a quantitative assessment for resilience. Some of the indicators are assessed across the entire landscape, while others are specific to only a subset (e.g. Floodplain Condition).

Three indicators (vertical heterogeneity, horizontal heterogeneity, and seral stage) do not have location-specific resilience assessments. For all three indicators, there are data to suggest how much heterogeneity and how many seral stages should be on the landscape, and how much there currently is, but there isn’t data to suggest where specifically each of these states or stages should be on the landscape. Therefore, the desired resilient condition for each of these indicators is to have proportions represented on the overall landscape similar to reference conditions.

The 21 indicators will be refined with Phase 2 of LRA. It should be noted that the indicators described here apply only to the LTW Project Area. The IADT did not evaluate resilience for the entire Analysis Area (which includes portions of the Tahoe and Eldorado National Forests) at this time because comparable data are not yet available for the Eldorado National Forest. However, where available, indictors are displayed in the Analysis Area using the same ranking as the Project Area.

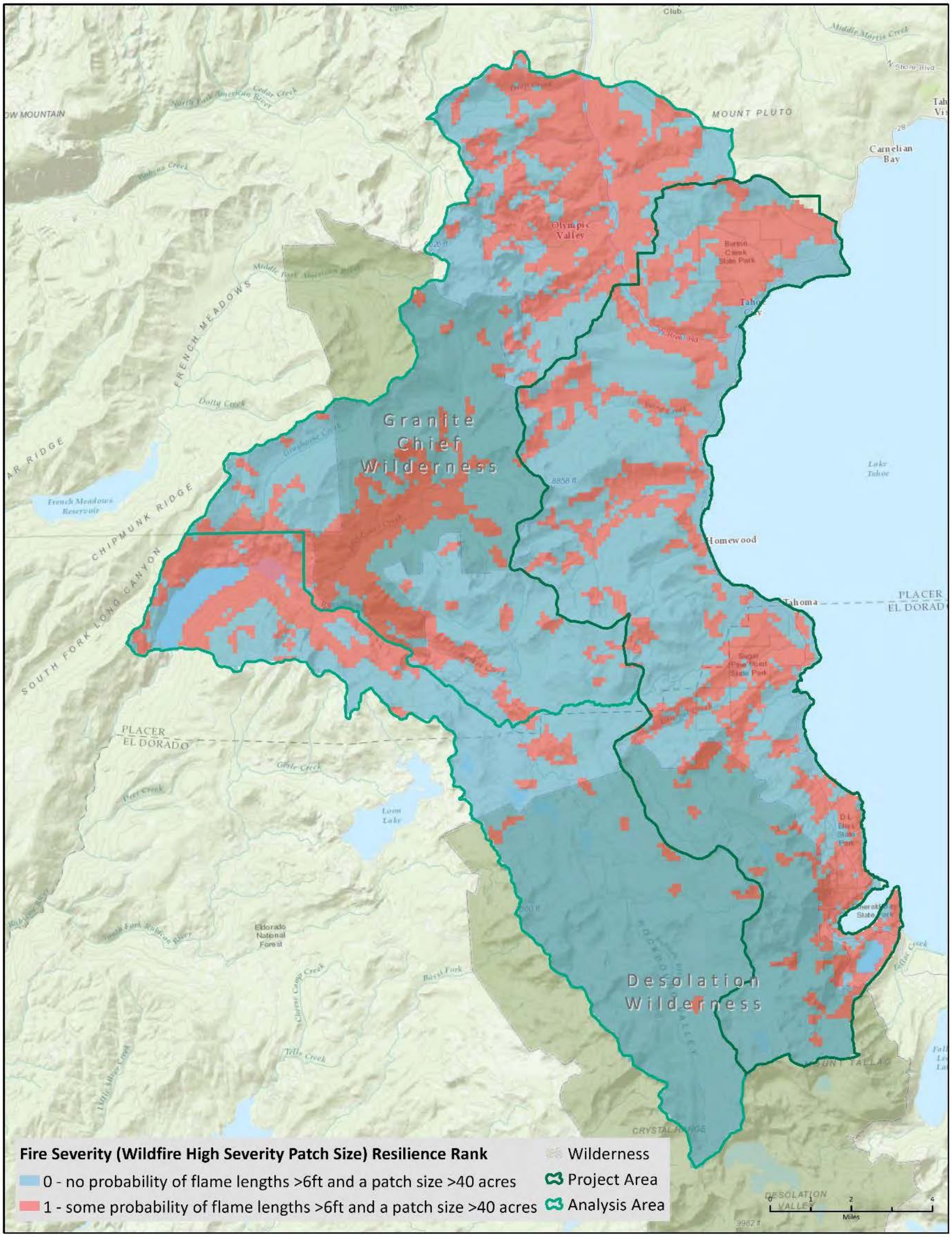
Indicators Assigned a Resilience Value

1. Mean Condition Class (Mean Fire Return Interval Departure Condition Class)



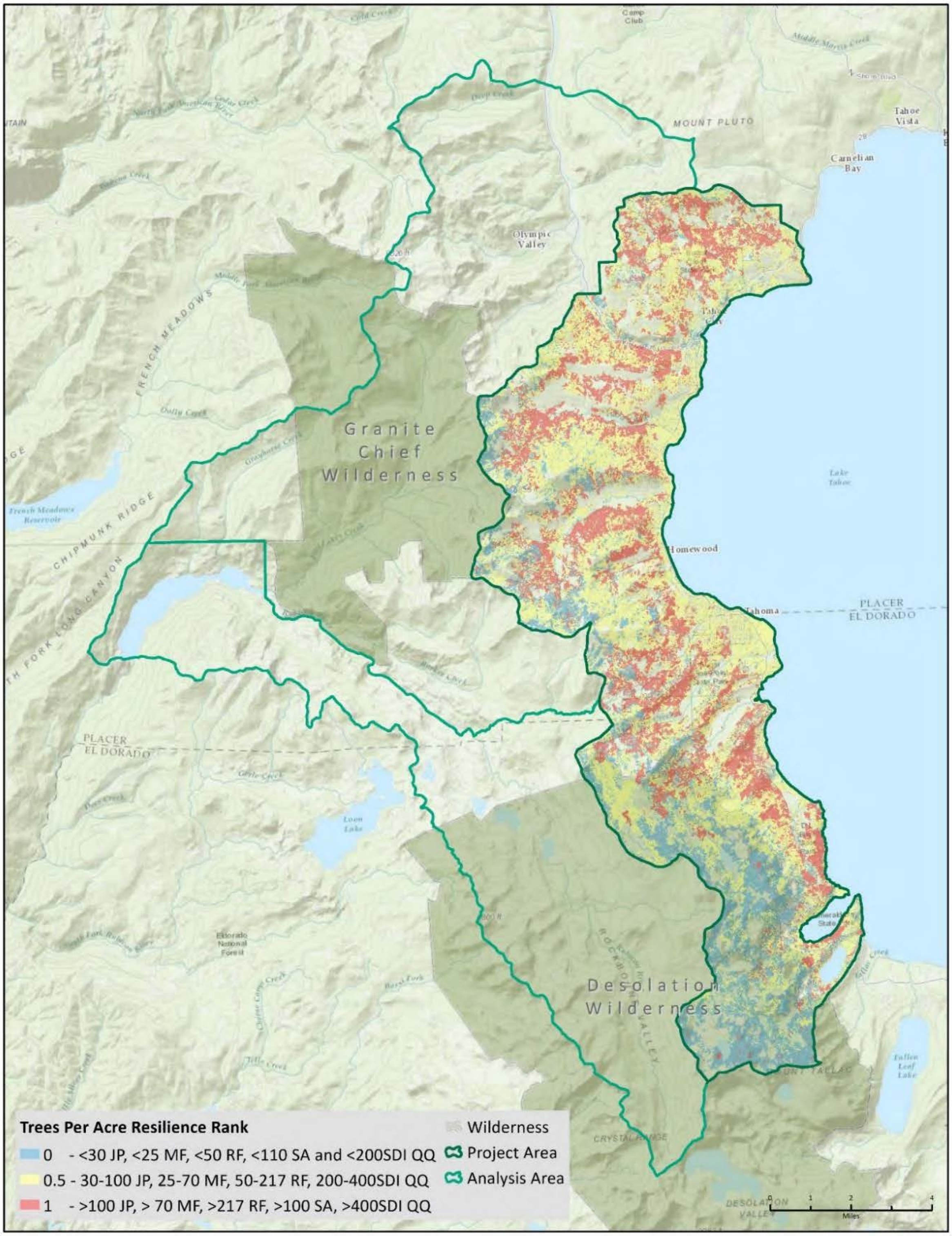
Indicator 1. Mean Condition Class is based on Fire Return Interval Departure (FRID) data for condition class. FRID gives an idea of where uncharacteristic fuels loads and tree densities may exist on the landscape. The resilient condition (0) is Condition Class 1, while the least resilient condition (1) is Condition Class 3, where the most natural fire cycles have been missed.

2. Fire Severity (Wildfire High Severity Patch Size)



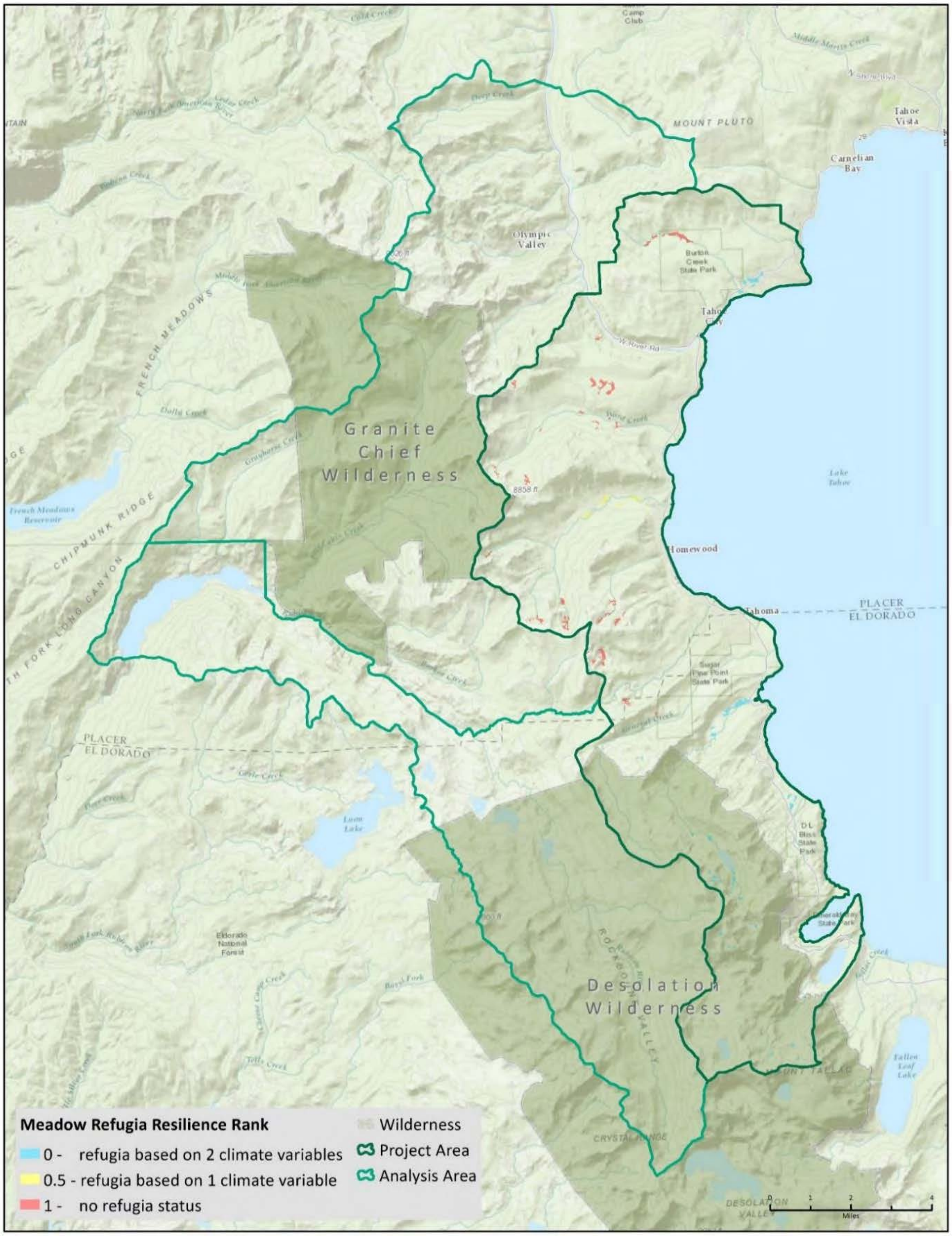
Indicator 2. Fire Severity identifies areas on the landscape that are more or less prone to large patches of high severity fire and high tree mortality. A flame length of greater than six feet is considered high severity. The resilient condition (0) is where patches of high severity fire would be less than 40 acres, while the least resilient condition (1) is where the patches would be greater than 40 acres.

3. Trees per Acre



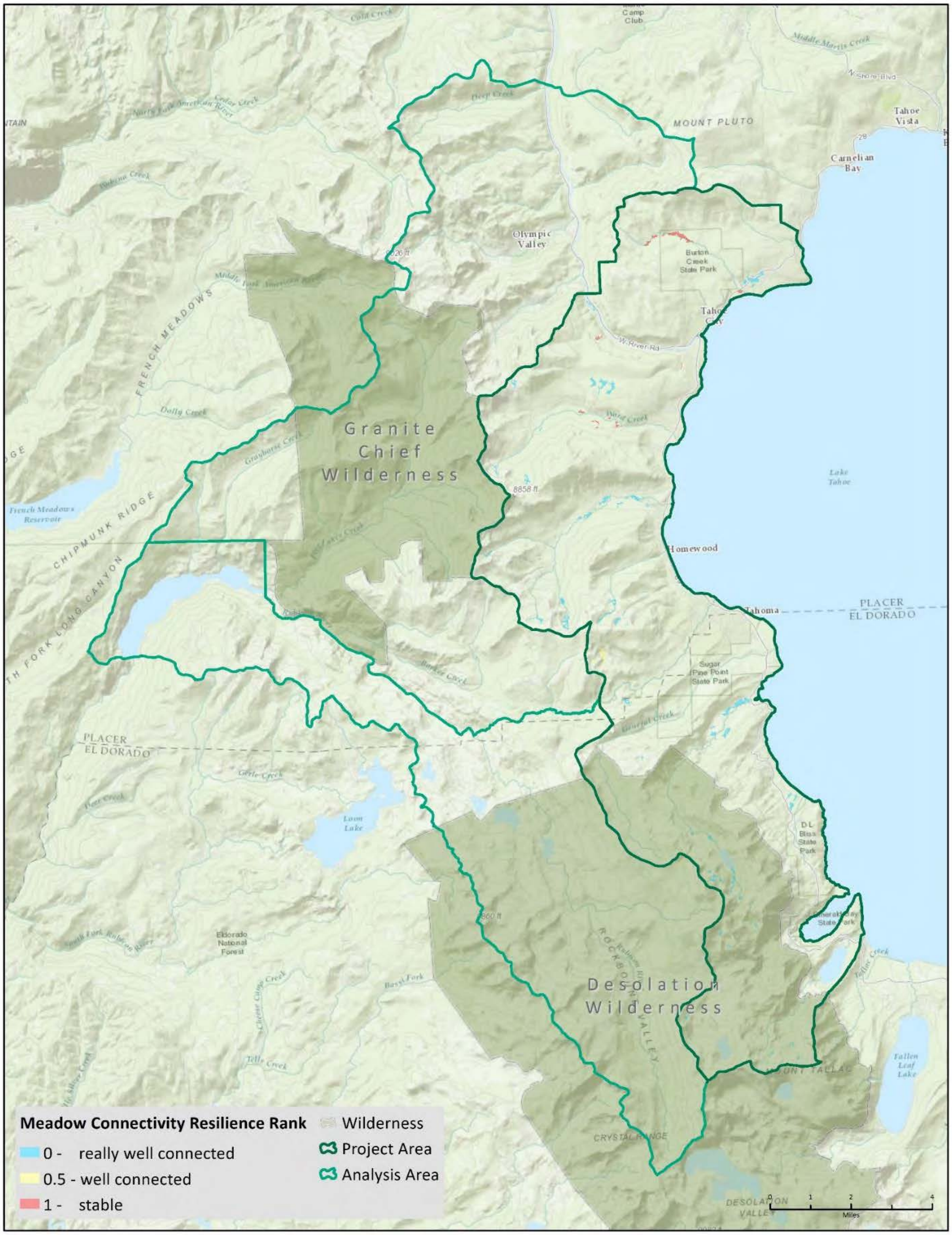
Indicator 3. Trees per Acre identifies areas on the landscape based on the number of trees per acre. The resilient condition (0) for each vegetation type (JP=Jeffrey pine, MF=mixed conifer, RF=red fir, SA=subalpine, QQ=aspen) is where the number of trees per acre is similar to the mean of reference data, less resilient (0.5) is where TPA exceeds mean reference conditions but the TPA are within the upper range of reference conditions, while the least resilient condition (1) is where the trees per acre exceeds reference condition that have been documented in the literature.

4. Meadow Refugia



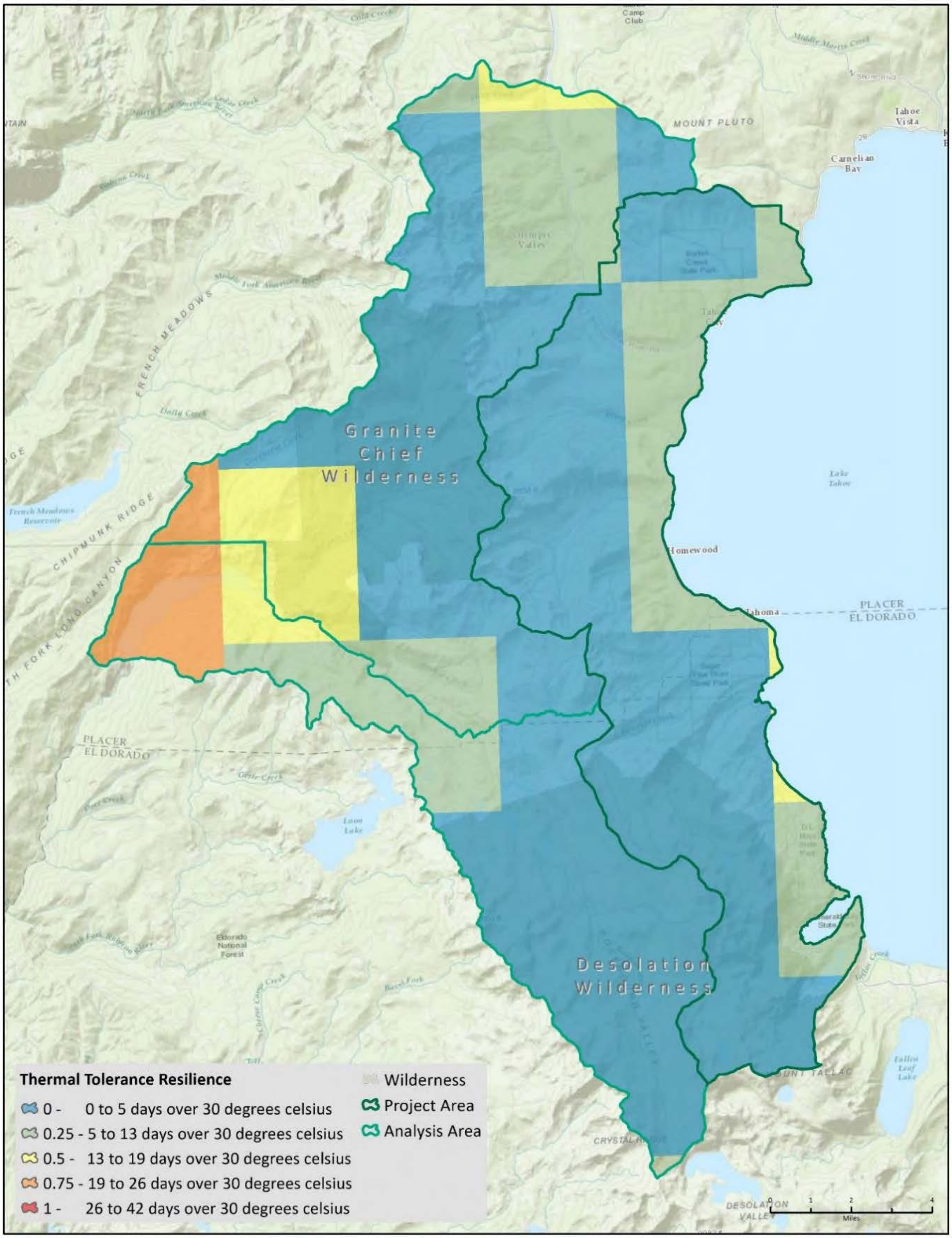
Indicator 4. Meadow refugia is based on the GFDL-A2 climate scenario, using annual precipitation and minimum temperature at the beginning of the modeling period 2010-2039 (Maher et al. 2017). Resilient (0) meadows are refugia based on two climate variables, less-resilient (0.5) meadows provide refugia based on one climate variable, and least-resilient (1) meadows do not provide refugia based on either climate variable.

5. Meadow Connectivity



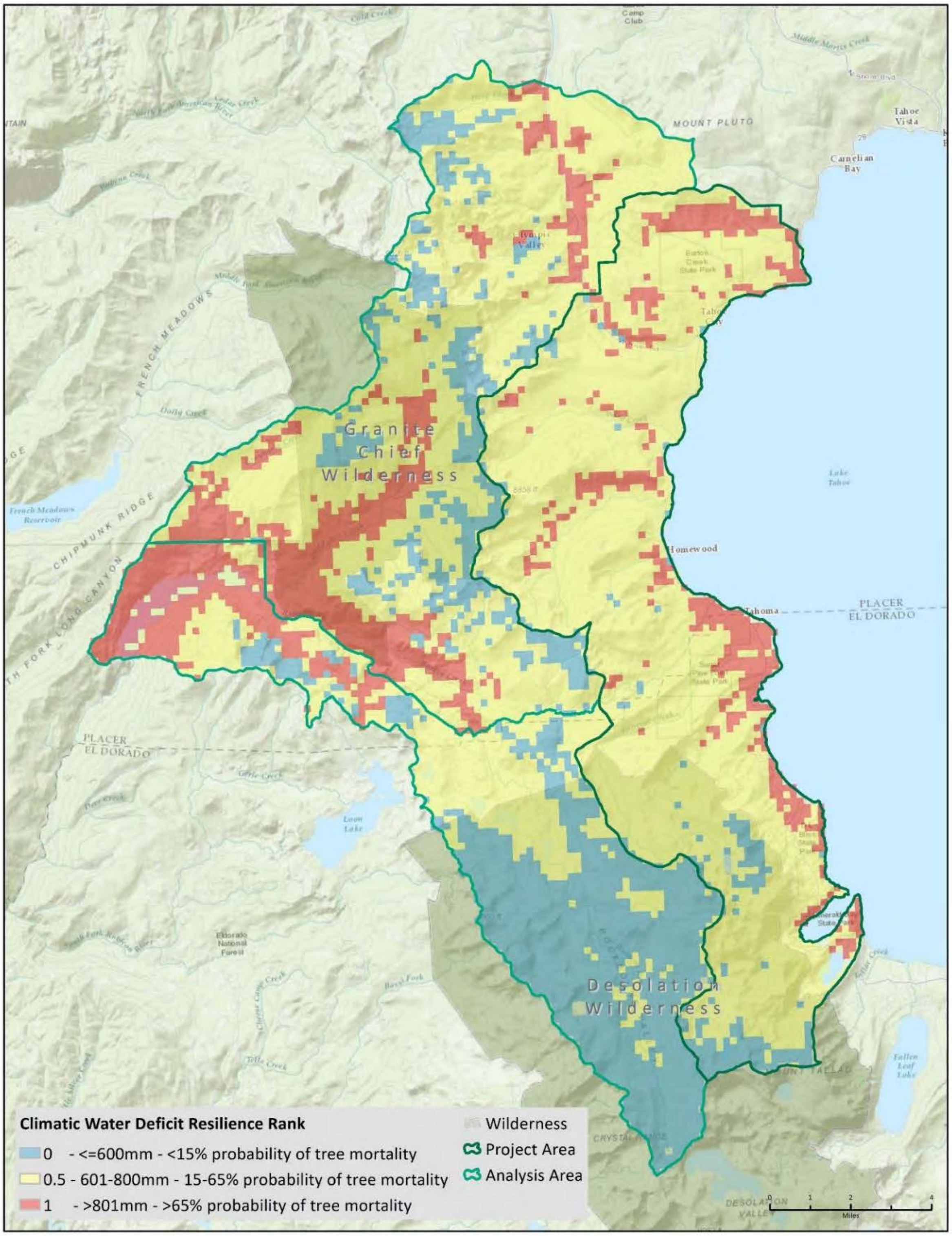
Indicator 5. Meadow Connectivity is assessed based on Maher et al. (2017). Sixty-two meadows are very well connected (resilient, 0), five are well connected (mid-resilient, 0.5), and 27 are "stable" or not connected (not resilient, 1).

6. Thermal Tolerance



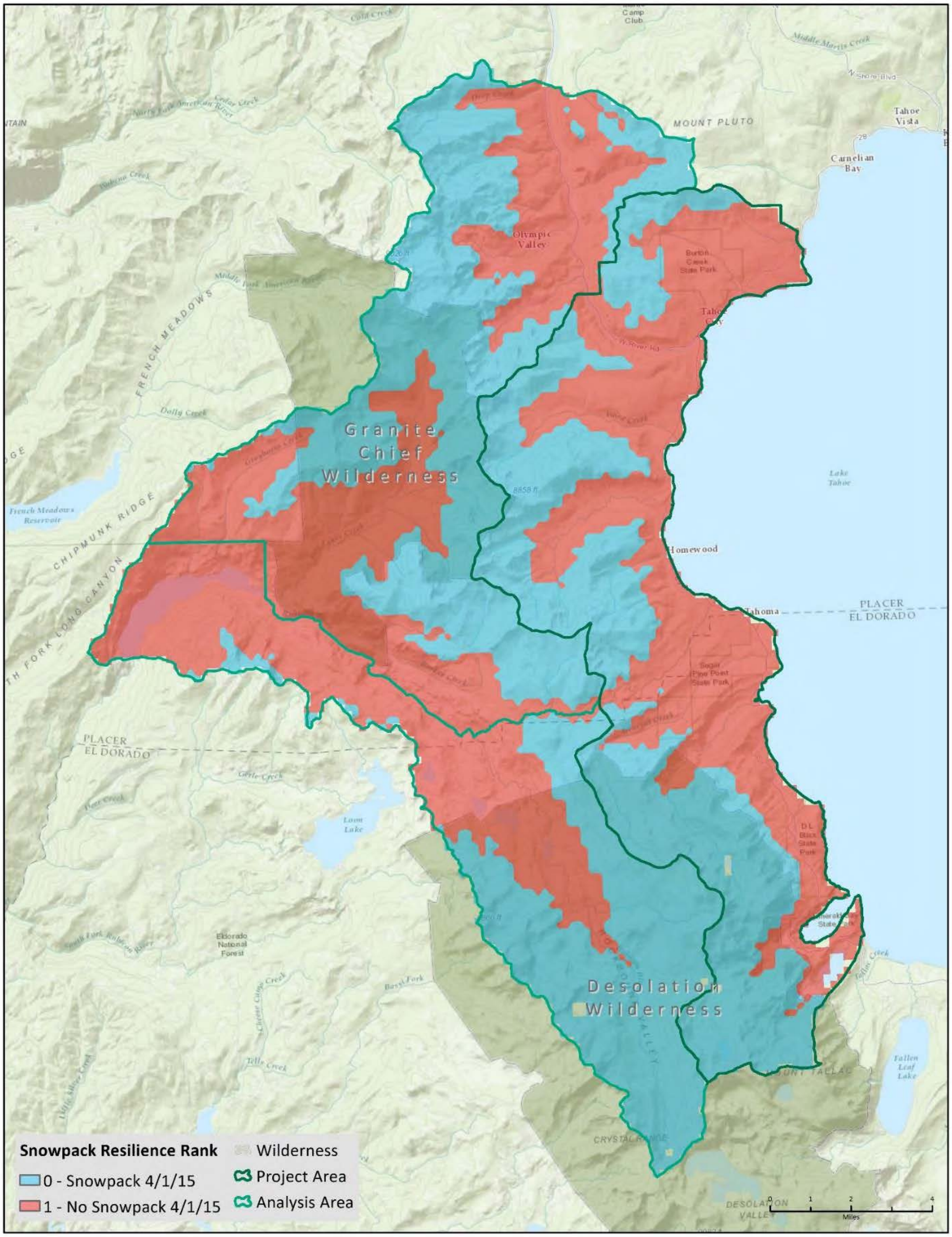
Indicator 6. Thermal tolerance is a measure of air temperature between May and September as it affects California Spotted Owl. This modeled output for 2025 shows areas of the landscape which can expect to have multiple days over 30° C. The resilient condition (0) is fewer days, while the least resilient condition (1), not present in the landscape, would have the hottest days.

7. Climatic Water Deficit



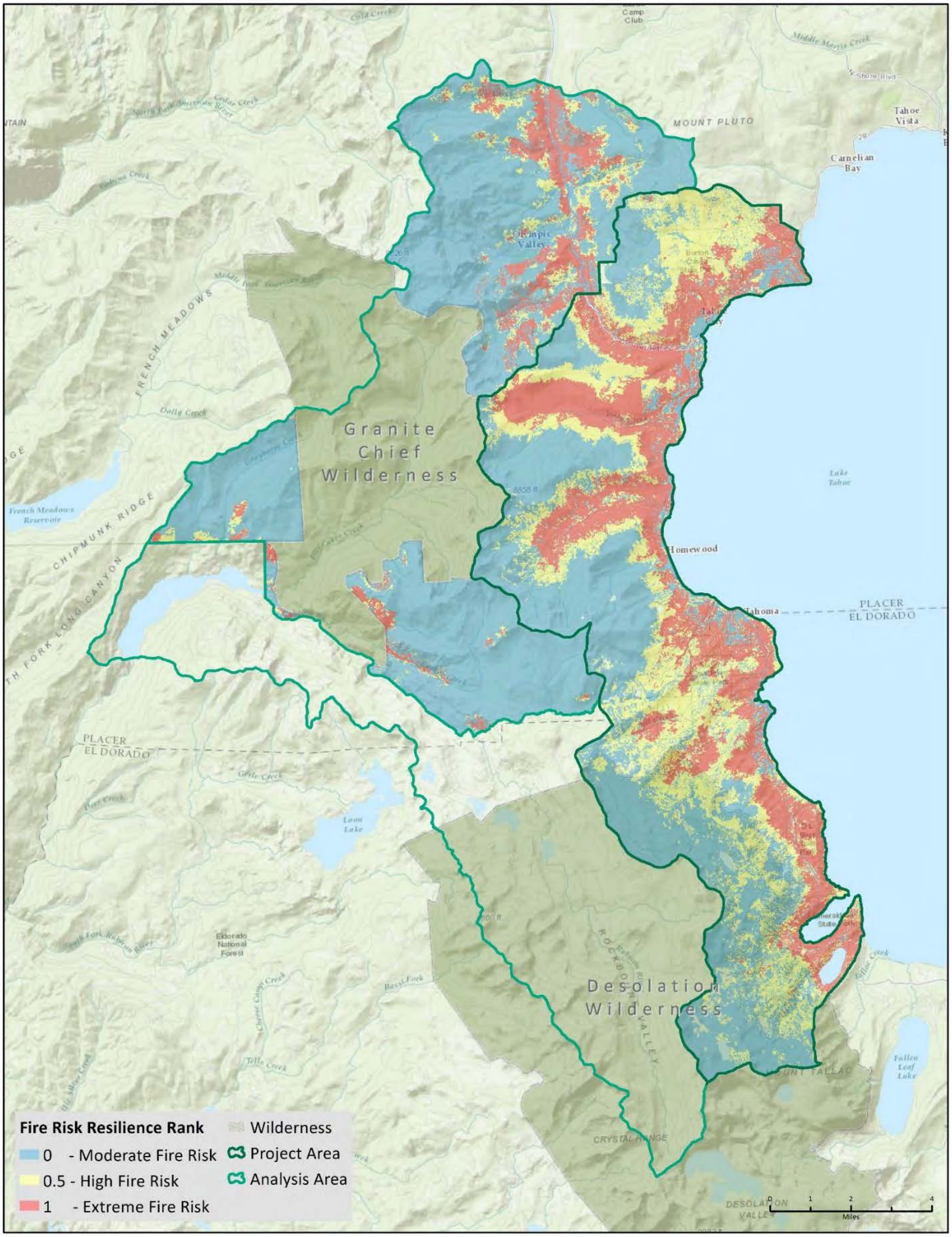
Indicator 7. Climatic Water Deficit (CWD) is a measure of plant stress. Resilience rank breaks are based on Restaino et al. (submitted). Ecosystems with higher CWD are less resilient to ecosystem disturbance (e.g. climate change, insects and disease, fire, etc.) and more likely to experience tree mortality.

8. Snowpack



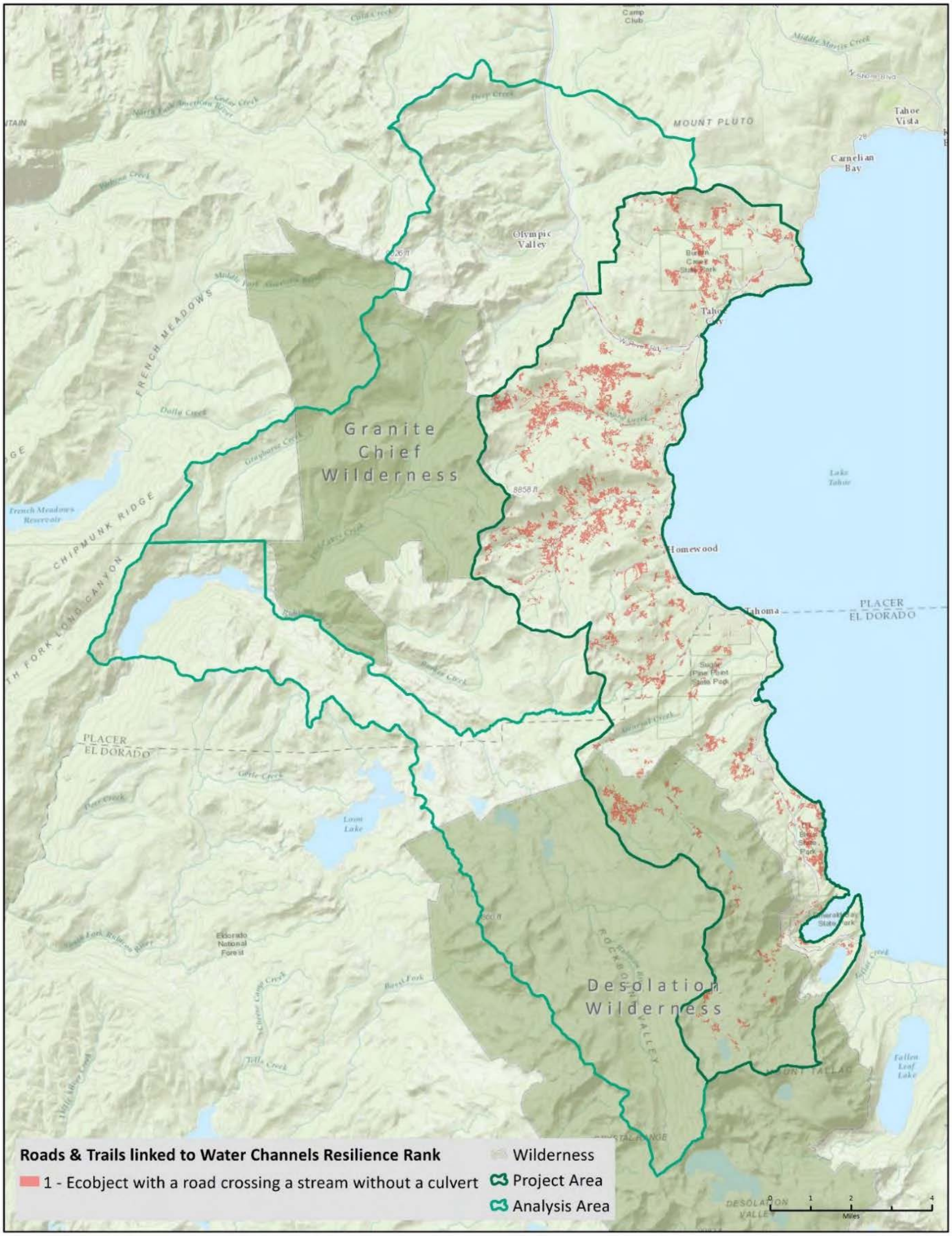
Indicator 8. Snowpack shows areas of the landscape where there was snow on April 1, 2015. All areas with snow on that date are considered resilient (0), all areas without snow on that date were considered least resilient (1).

9. Fire Risk Index



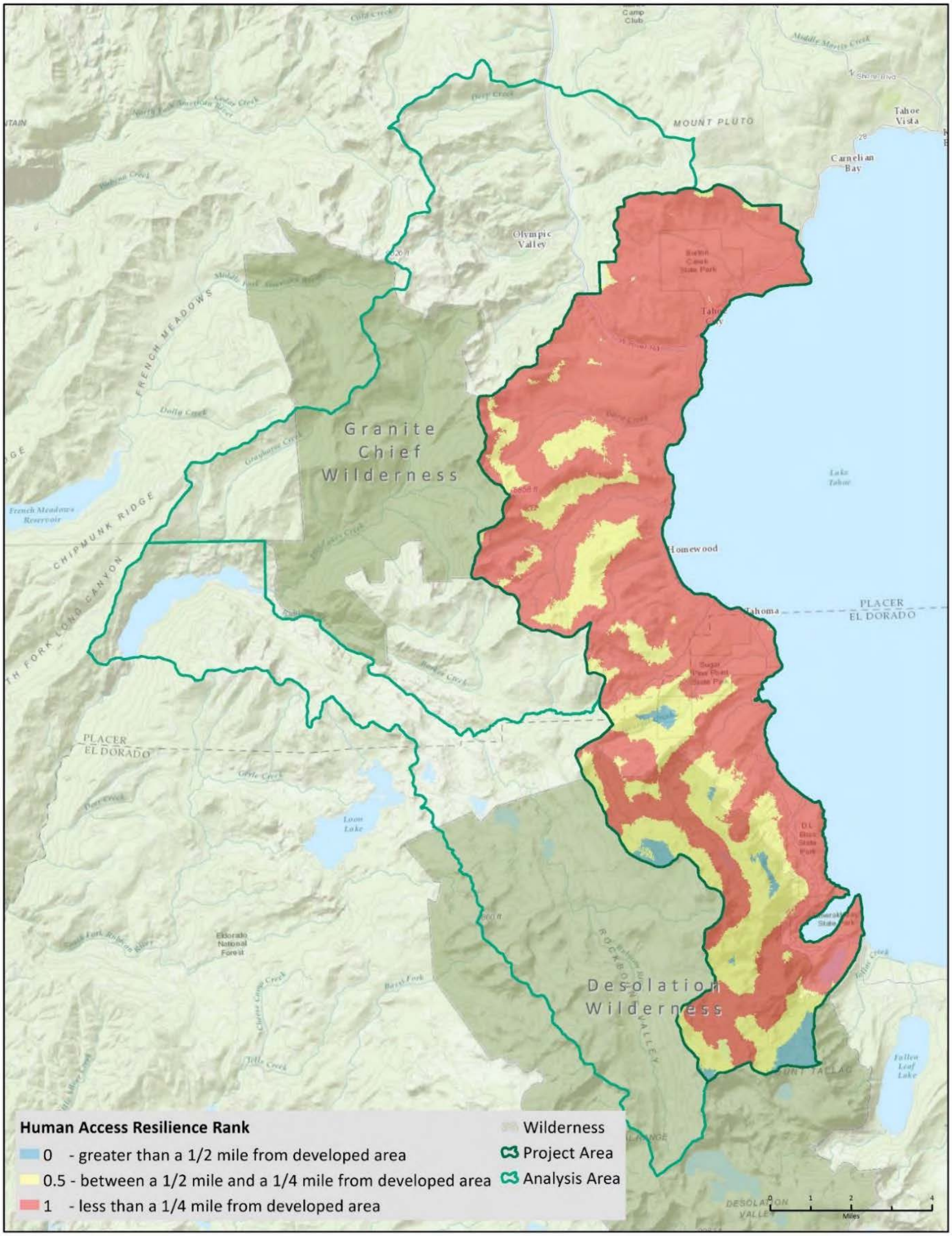
Indicator 9. Fire risk index measures the relative risk of human populations and infrastructure to the threat of wildland fire. It indicates areas of greatest concern for wildland fire management and fuel reduction.

10. Roads and Trails Linked to Water Channels



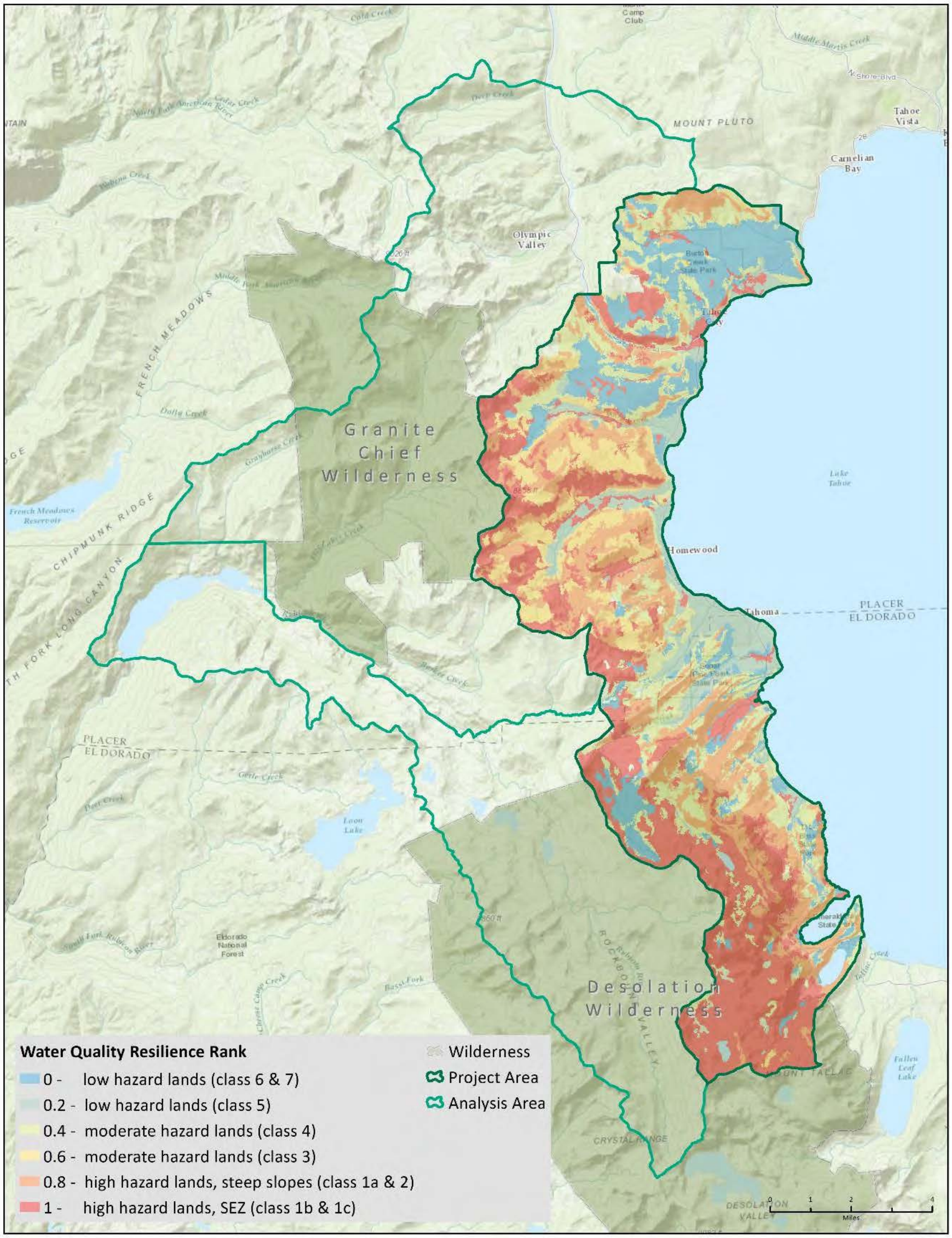
Indicator 10. Roads and trails identifies locations where a water channel crosses a road or trail without a culvert. EcObjects are considered least-resilient (1) if there was no culvert, and resilient (0) for EcObjects with a culvert crossing, although the condition of the culverts are unknown.

11. Human Access



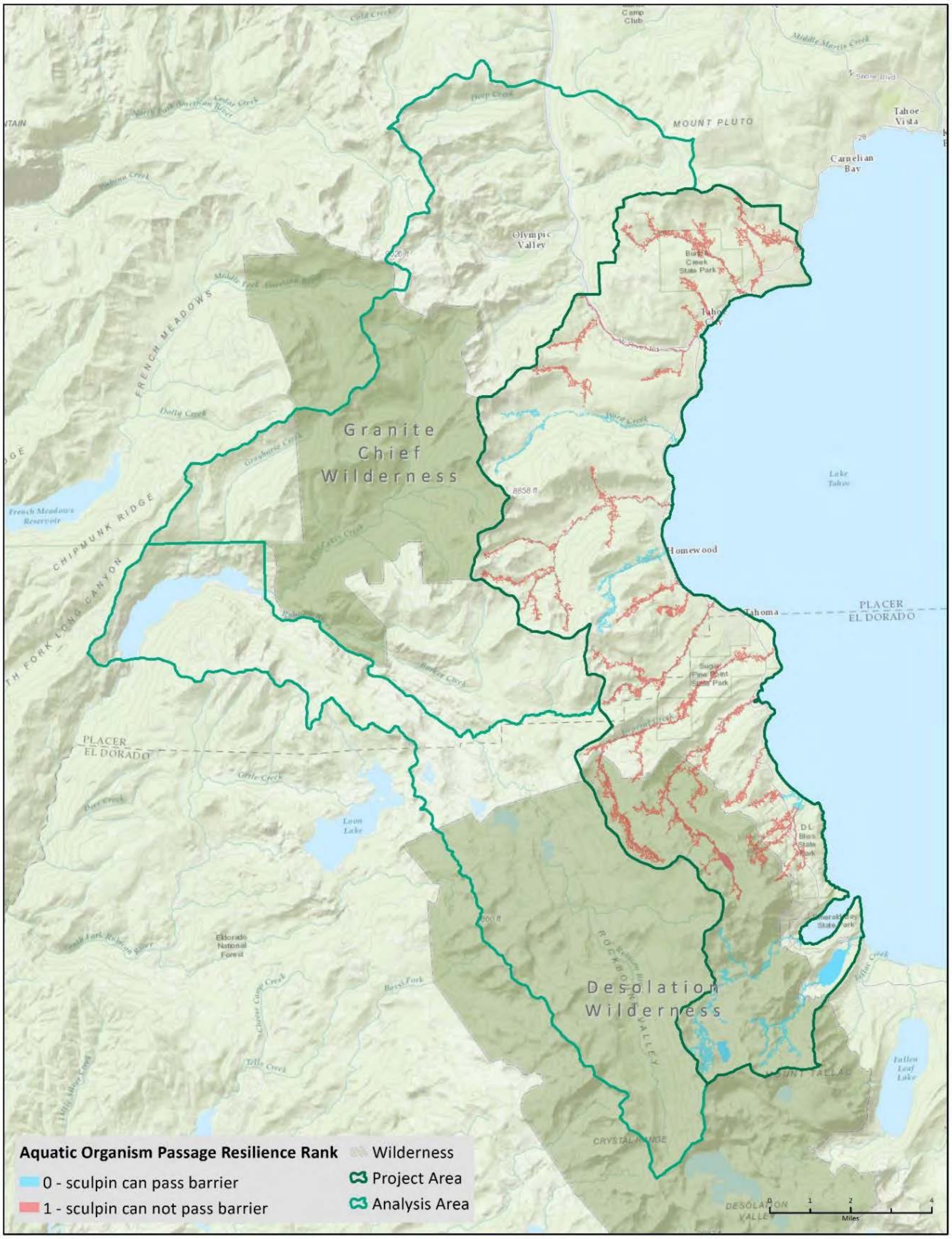
Indicator 11. Human access is intended to identify areas of the landscape that are most impacted by noise and presence associated with human use. The IADT classified trail and road buffers as follows: resilient habitat (0) is > ½ mile from road or trail, less resilient habitat (0.5) is ¼ mile to ½ mile, and least resilient habitat (1) is < ¼ mile of a road or trail.

12. Water Quality



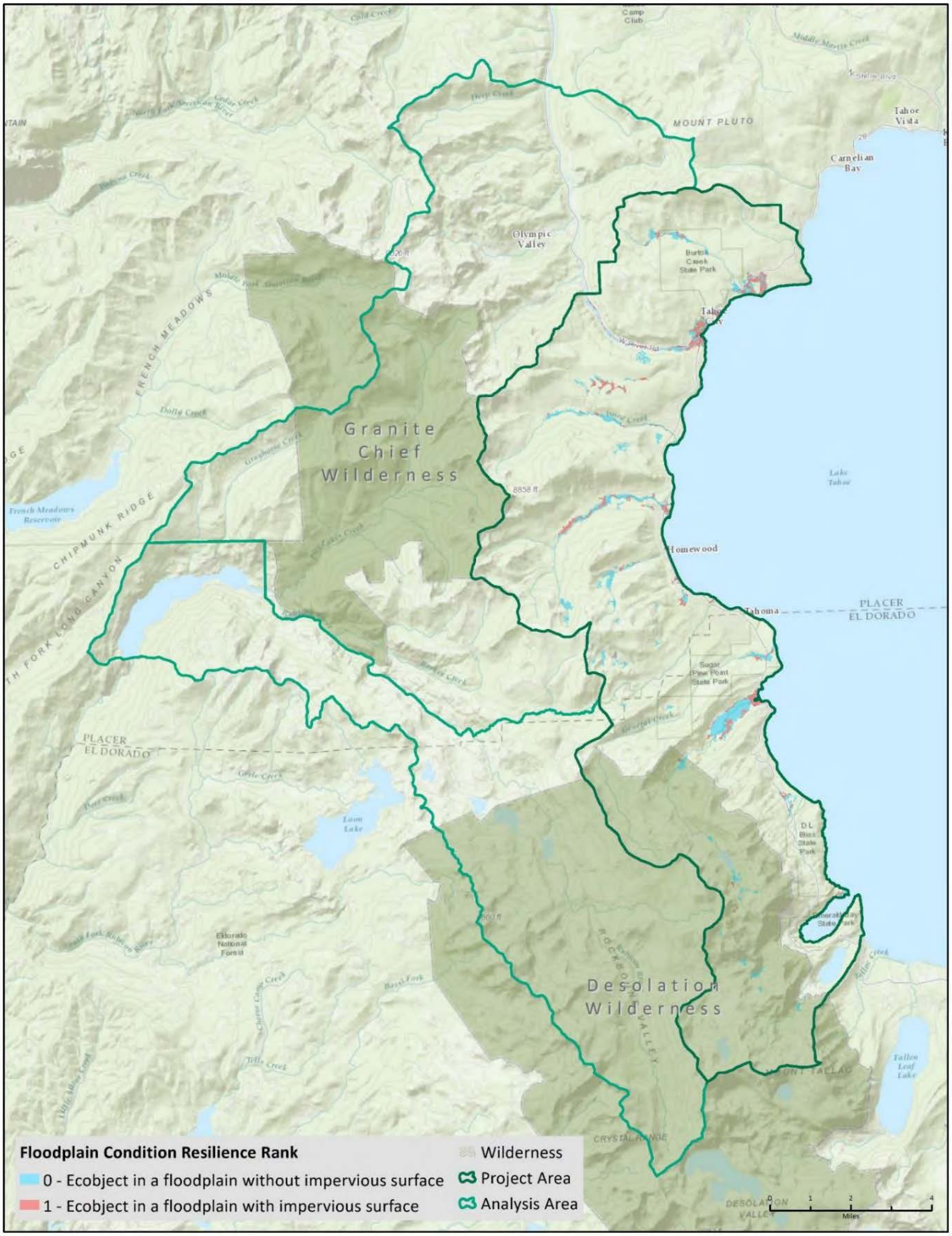
Indicator 12. Water quality is based upon the Bailey's Land Capability Classification System, which combines hazard ratings based upon soil type, slope, infiltration rates and a hazard rating based upon geomorphic setting to assign a land capability score, ranked 1-7. A resilience rank was assigned for each class based upon the relative hazard (High, moderate or low hazard lands and the percent of allowable disturbance for each), with the resilient (0) for low hazards, and least resilient (1) for high hazards.

13. Aquatic Organism Passage



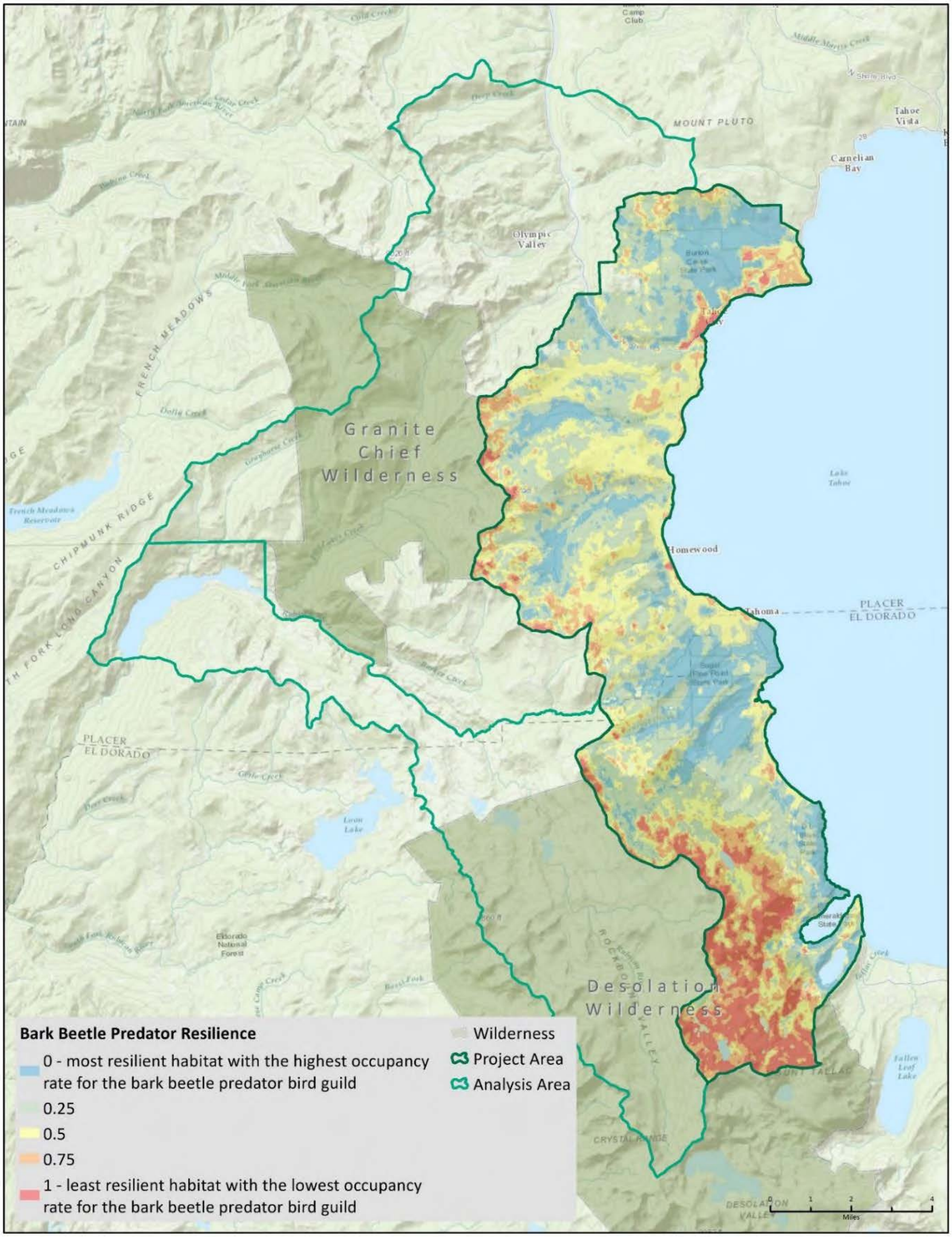
Indicator 13. Aquatic organism passage measures the number of man-made barriers to sculpin movement, the lowest barrier threshold for native fish, in each stream in the LTW Project Area. Streams with no man-made barriers are assumed to have a higher amount of aquatic organism connectivity. If a stream does not have a man-made barrier or sculpin can pass the barrier, it received a resilience rank of 0. If the stream contains a barrier that cannot pass sculpin, it was assigned a resilience rank of 1 (least resilient).

14. Floodplain Condition



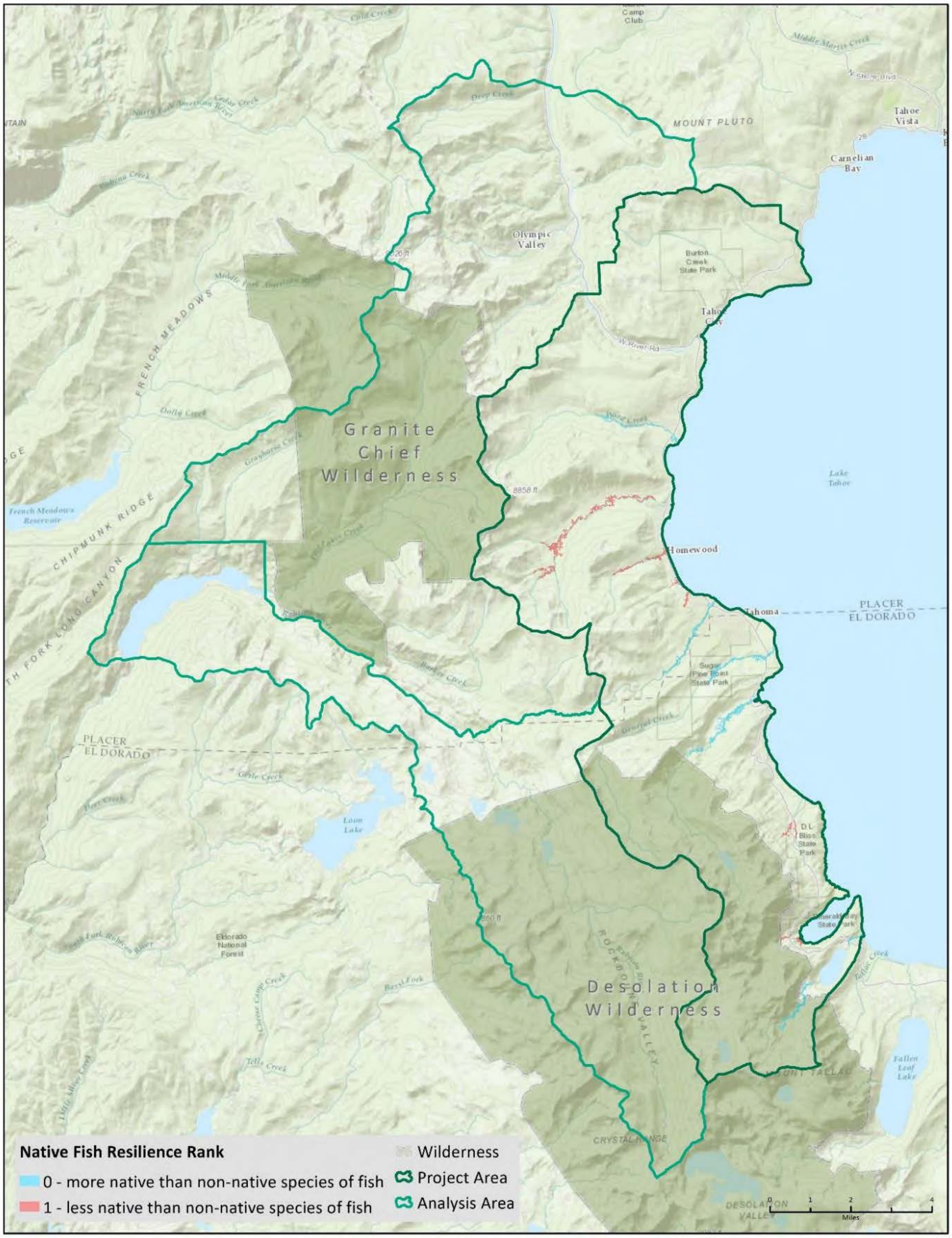
Indicator 14. Floodplain condition illustrates areas of floodplain where encroachment of impervious coverage impedes natural functions. Floodplain/SEZ EcObjects that do not contain impervious surfaces are considered resilient (0), while EcObjects that do contain impervious surfaces are considered least resilient (1). The remainder of the Project Area (non-floodplain) was not assessed.

15. Bark Beetle Predators



Indicator 15. Cavity nesting birds act as a biological control agent on bark beetles to moderate and reduce the effects of insect outbreaks and promote forest resilience. Resilient areas (0) are areas with the highest probability of occurrence for all cavity nesting bird species assessed in the project area, while least-resilient (1) has the lowest probability for cavity nesters.

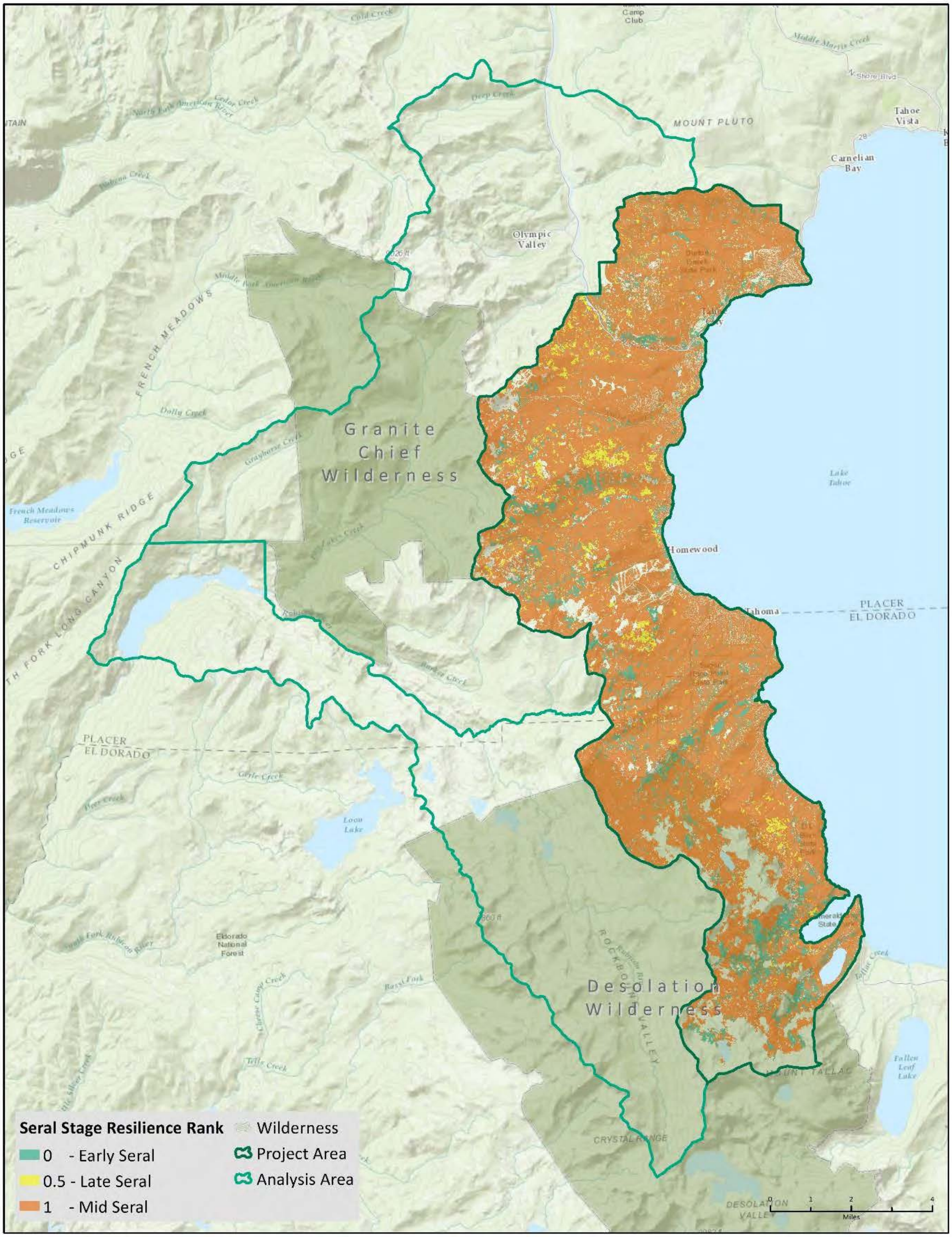
16. Native Fish Diversity



Indicator 16. Native fish diversity is an indicator of habitat quality, connectivity, and complexity. Streams with a greater ratio of native species than non-native species are more resilient to disturbances. For this indicator streams that have more native species than non-native species are considered resilient (0), all other streams are least resilient (1).

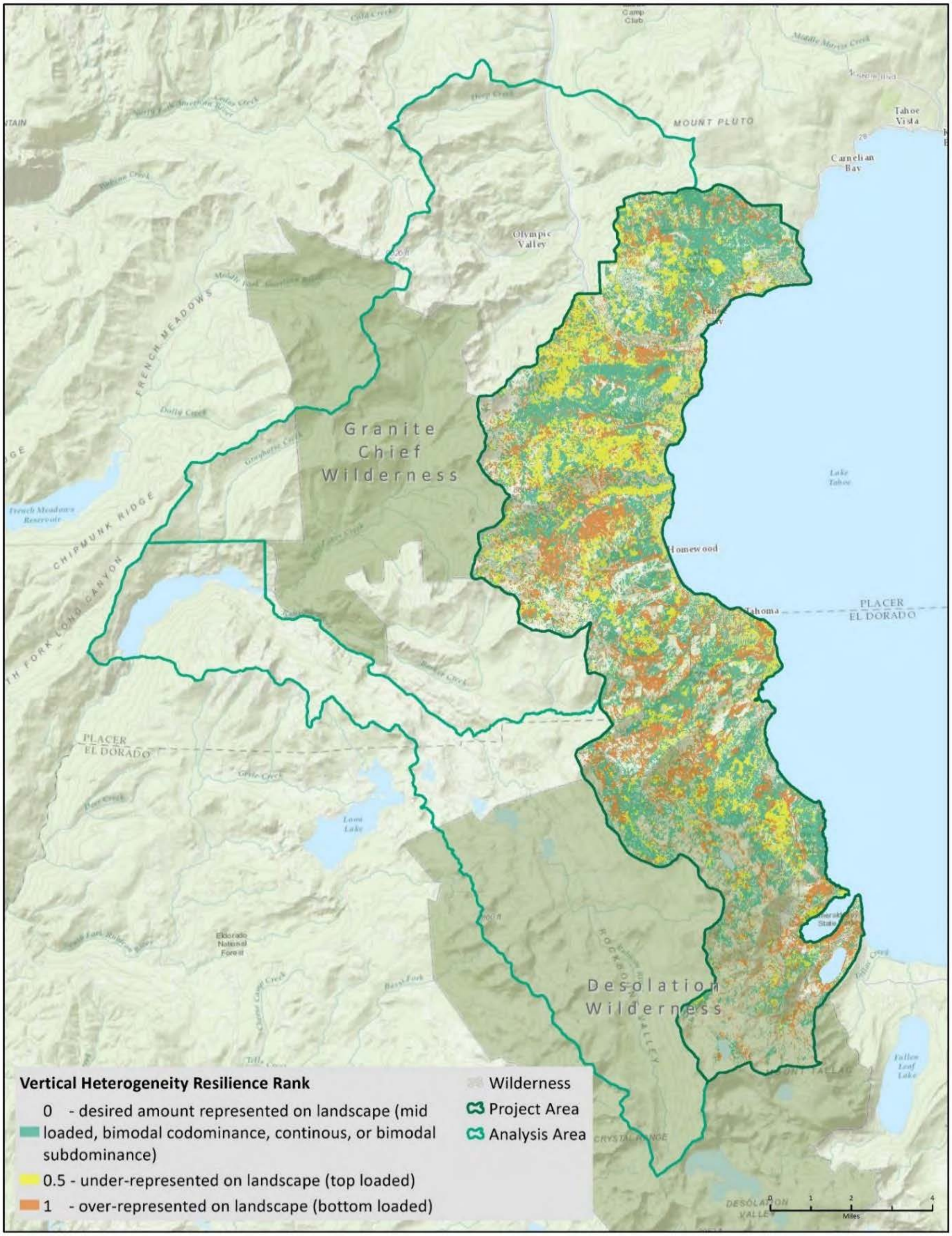
Indicators with proportional resilience values

17. Seral Stage



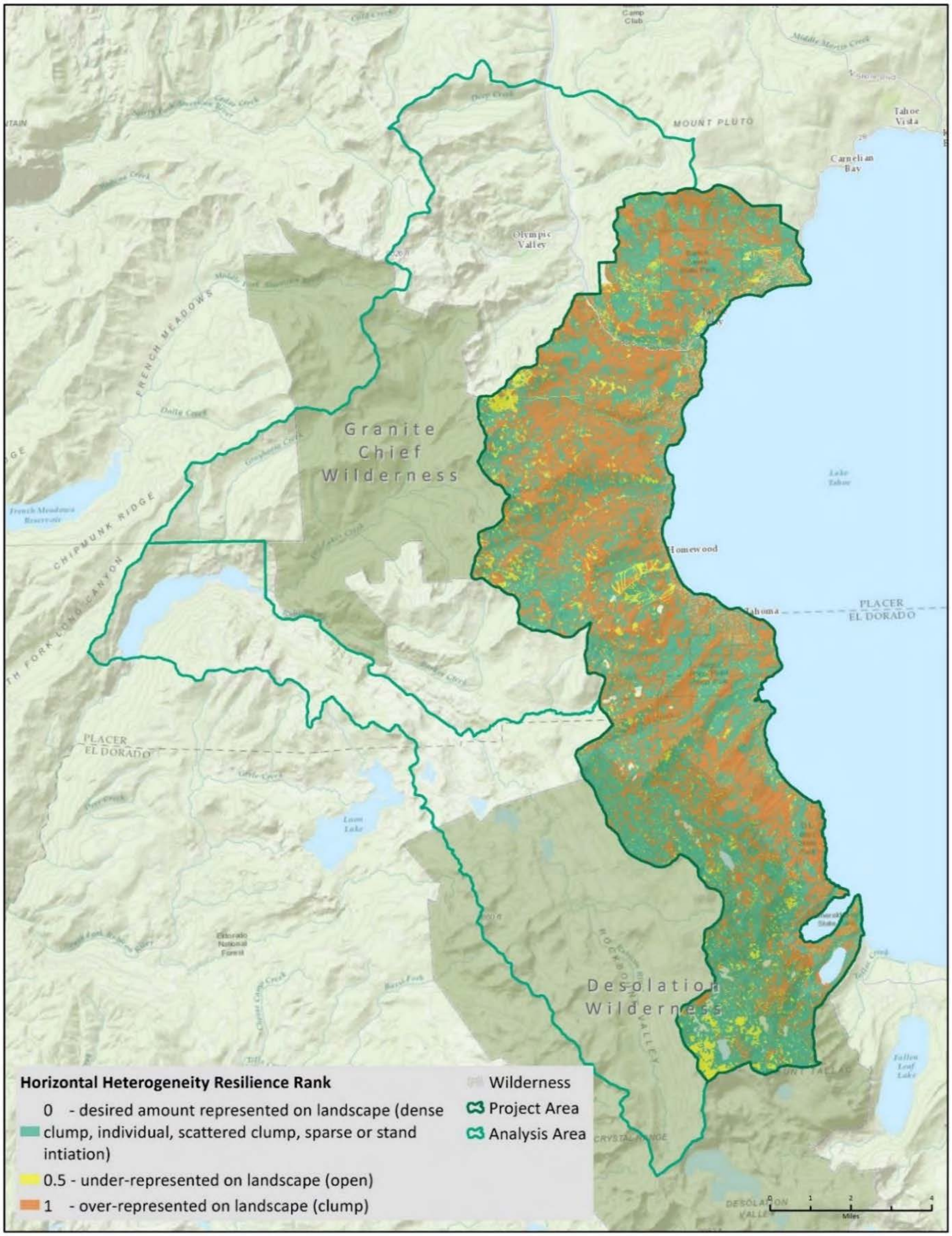
Indicator 17. Seral Stage proportions compared to desired resilient condition for red fir, mixed conifer, and yellow pine. A value of 1 indicates over-represented on the landscape, 0.5 is under-represented, and 0 signifies appropriately represented.

18. Vertical Heterogeneity



Indicator 18. Vertical Heterogeneity spatial patterns are important resilience indicators because they influence disturbance behavior, regeneration, snow retention, and habitat quality. For forested vegetation types, a value of 1 indicates bottom loaded which is over-represented on the landscape, 0.5 signifies under-representation in this case top loaded, and 0 signifies the remaining classes which are appropriately represented.

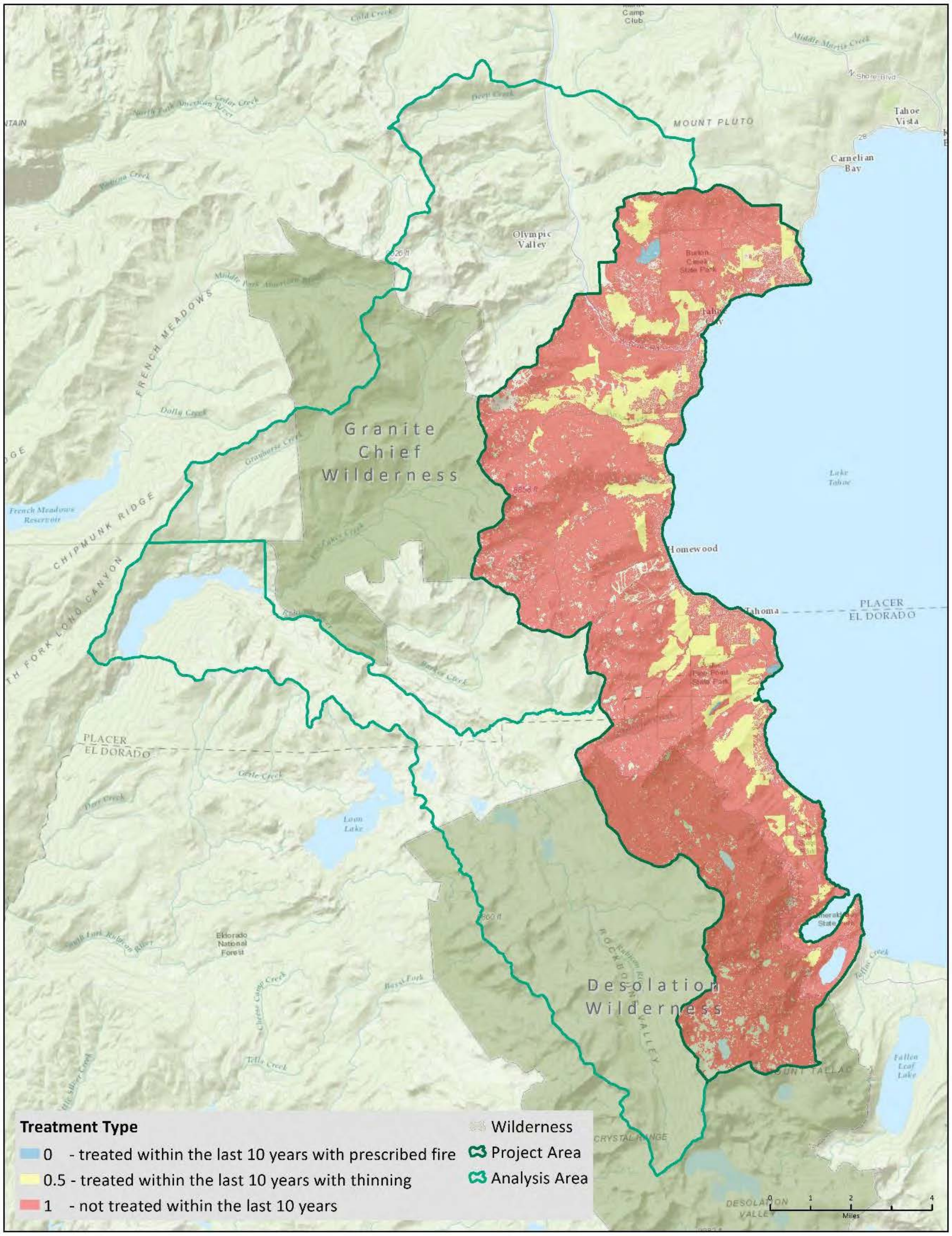
19. Horizontal Heterogeneity



Indicator 19. Horizontal Heterogeneity is a measure of spatial variation of trees. Across the landscape there is an over-representation of clumps (1 or least resilient) across all land management units and an under-representation of open (0.5 or less resilient).

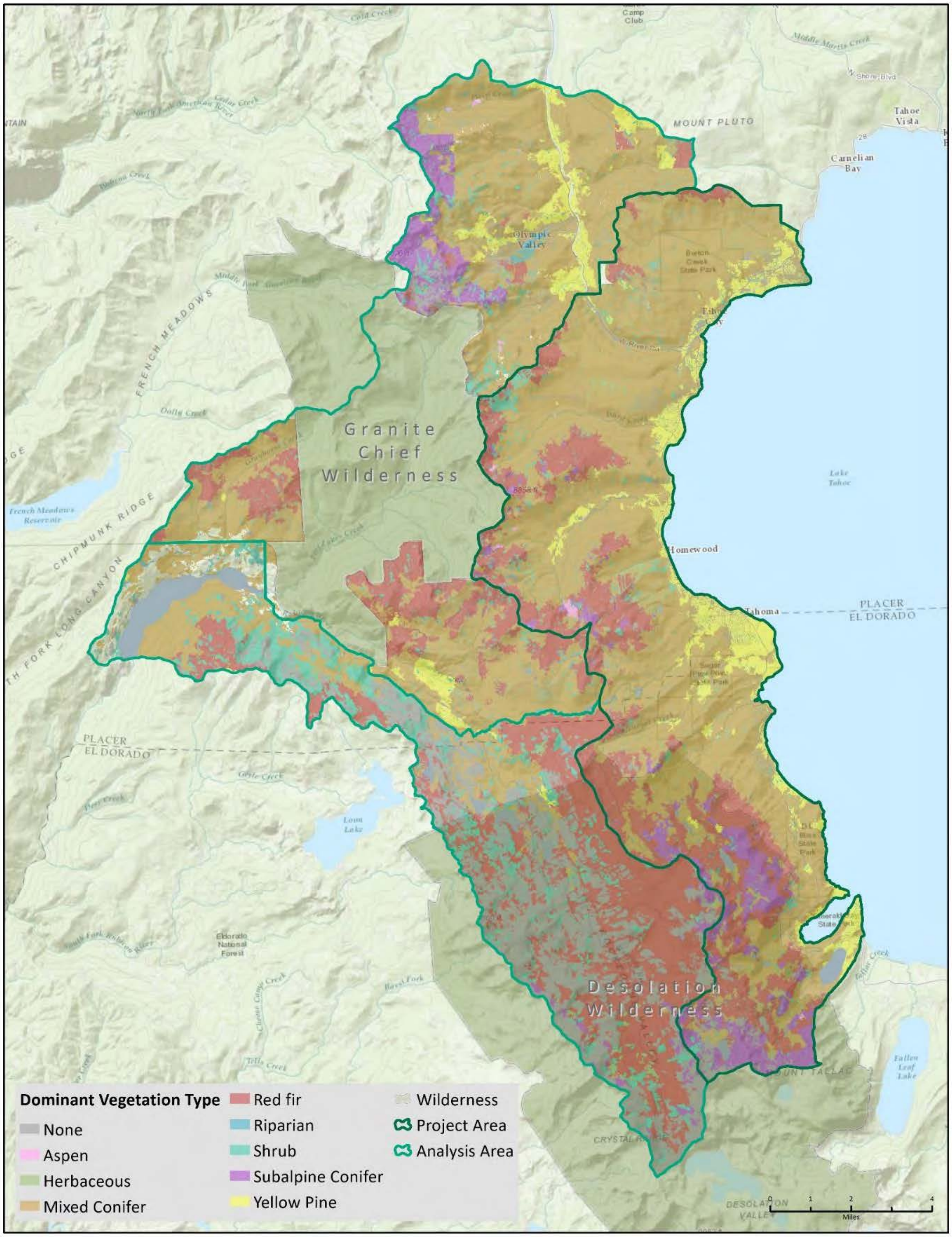
Visual Overlay Indicators

20. Treatment Type



Indicator 20. Treatment type incorporates all management actions including prescribed fires (rank 0), and mechanical and hand thinning (rank 0.5) including pile burning. These treatments are important to visually illustrate on a map but do not tell us if these treated areas are now resilient (or conversely, that untreated areas are not resilient).

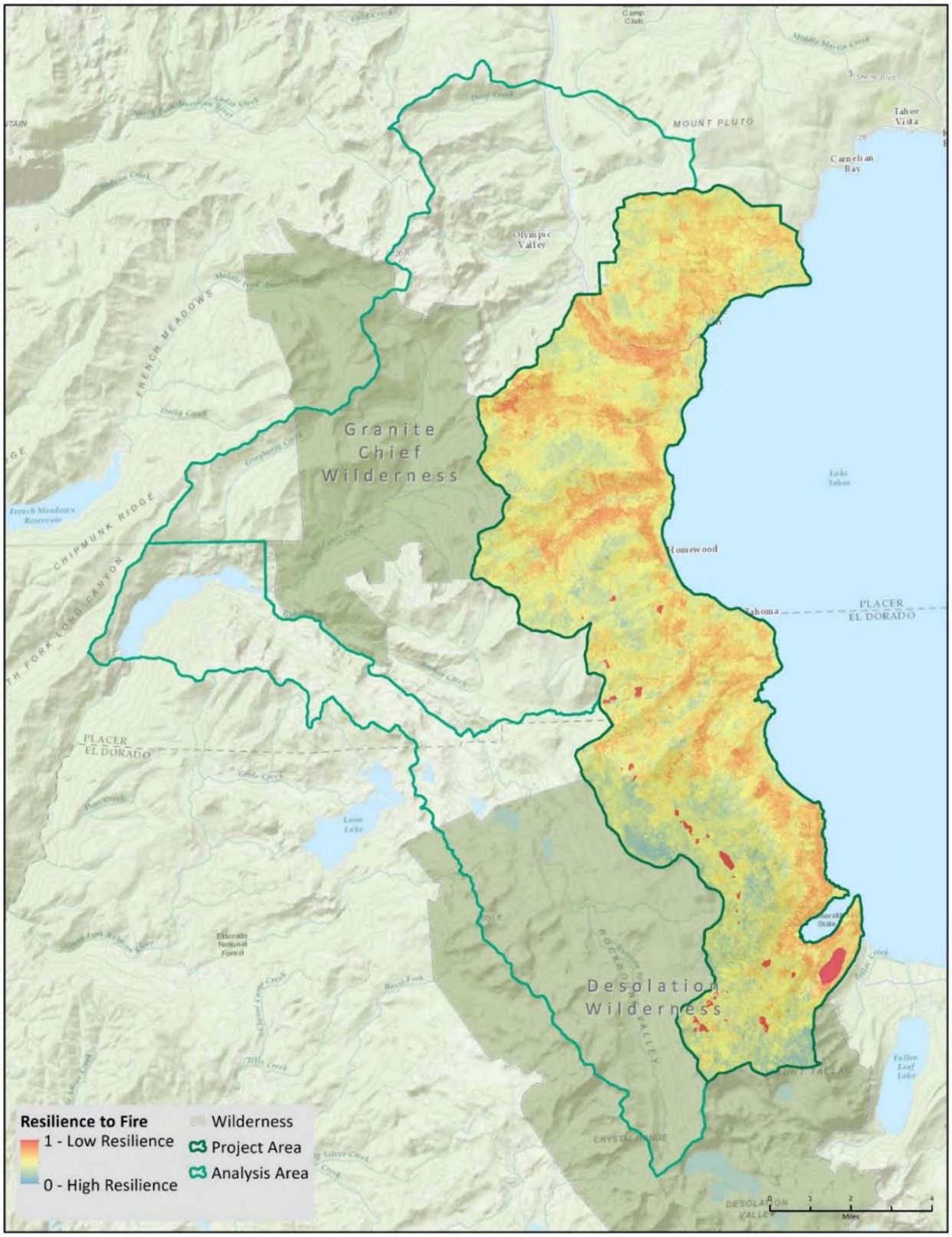
21. Vegetation Type



Indicator 21. Vegetation Type: a diverse representation of vegetation types across the landscape will increase resilience because different vegetation communities respond differently to type and magnitude of disturbance. There is more mixed conifer on the landscape than would be expected under the natural range of variation, however this indicator is only an overlay at this time.

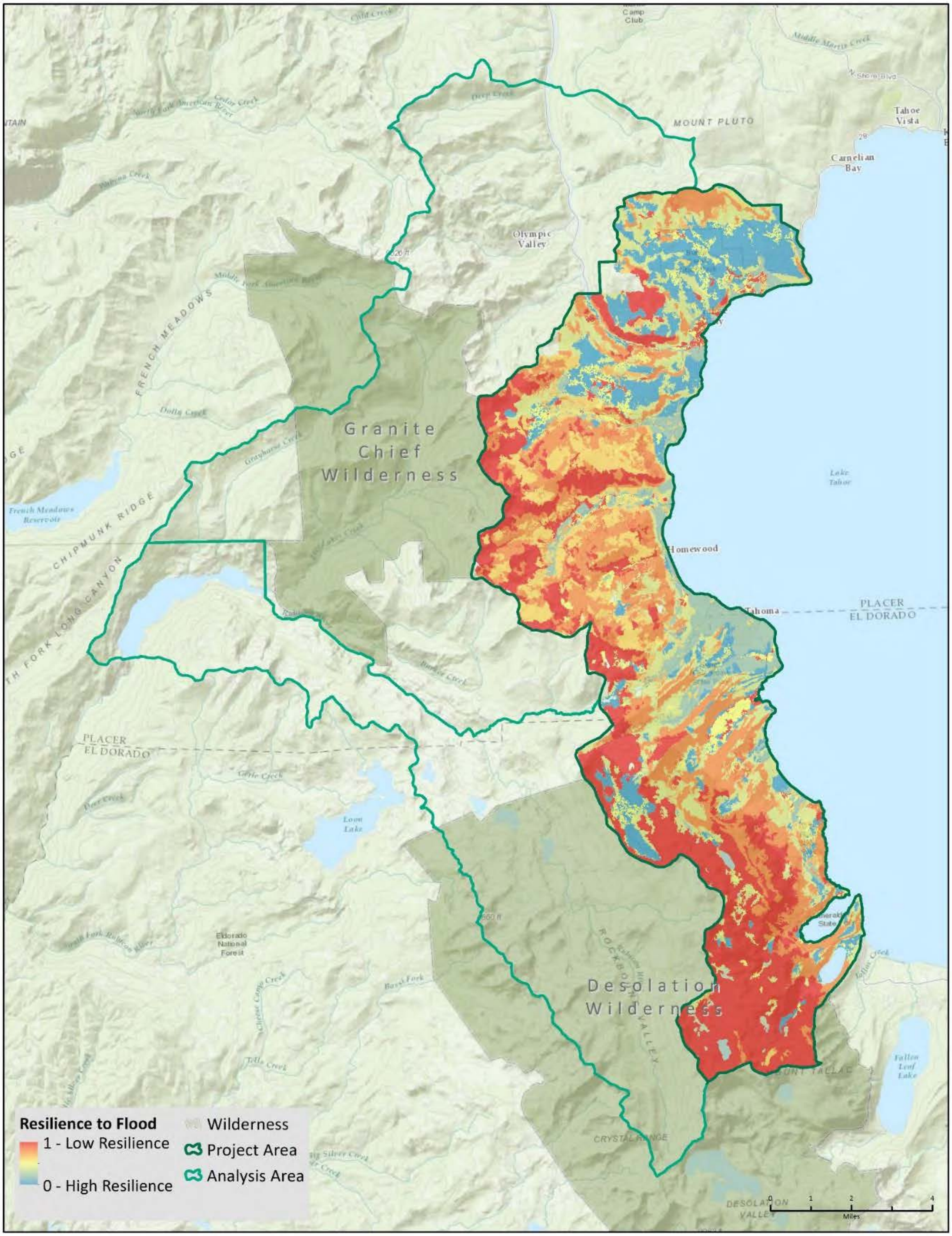
Composite Indicators

A. Resilience to Fire



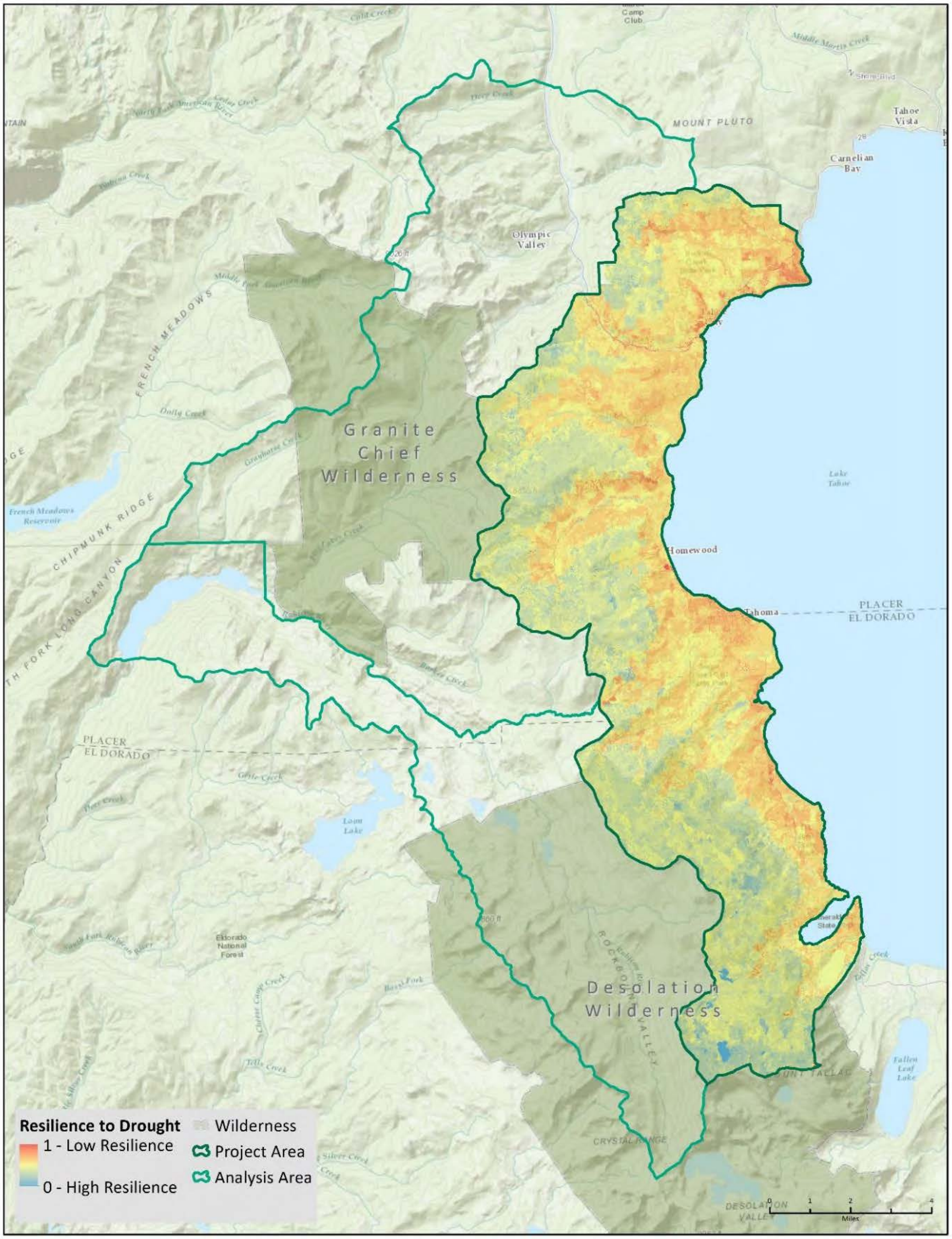
Composite A. Resilience to Fire composite indicator include: Mean Condition Class, Fire Severity, Trees per Acre, Fire Risk Index, Roads and Trails Linked to Water Channels, Human Access, Water Quality, Seral Stage (Proportional), Vertical Heterogeneity (Proportional), and Horizontal Heterogeneity (Proportional). Note that the ranking of lakes as least resilient in this composite indicator is because only one indicator (human access) was evaluated for the water bodies, and therefore this reflects only this indicator and should not be considered truly as least resilient.

B. Resilience to Flood



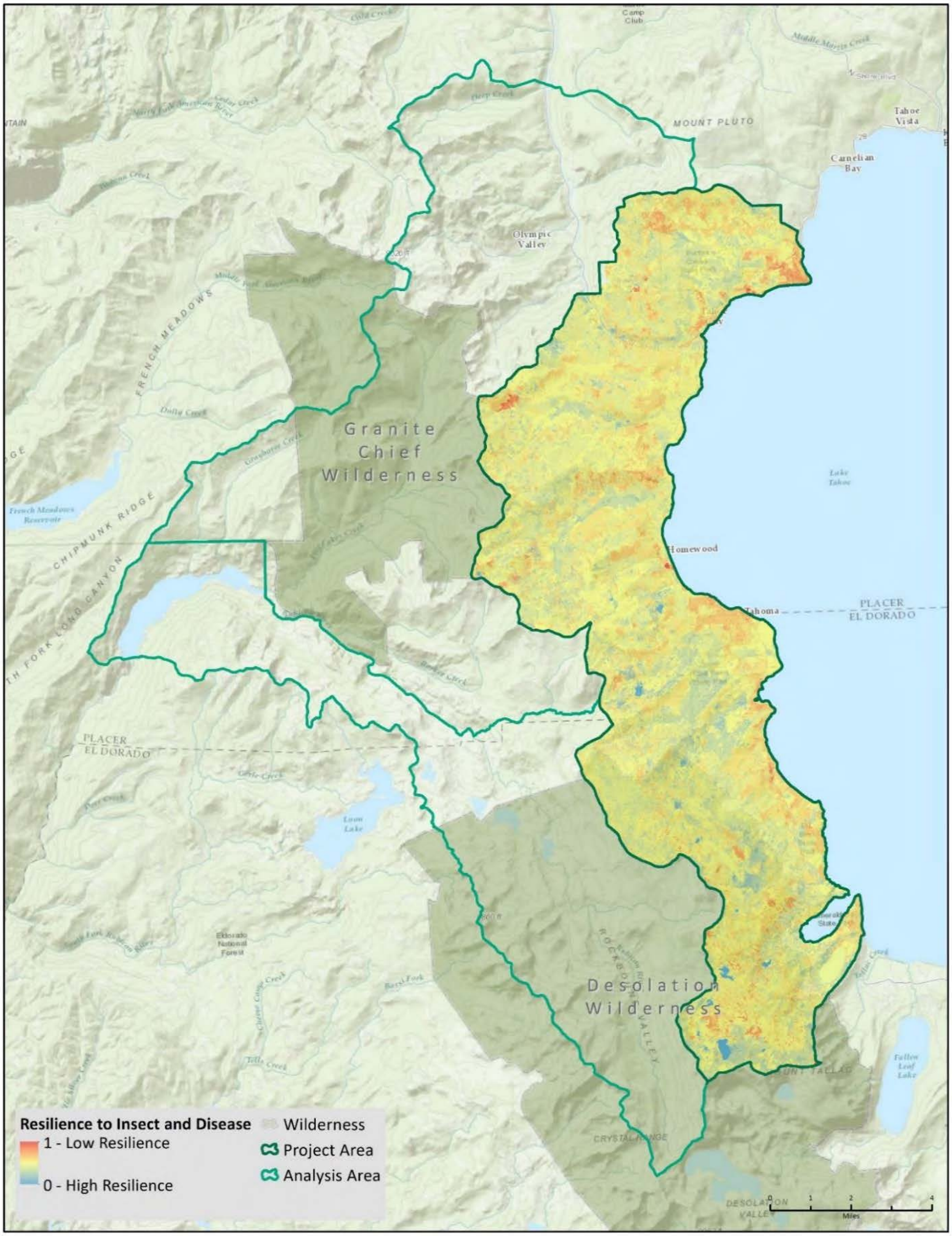
Composite B. Resilience to Flood composite indicator includes: Roads and Trails Linked to Water Channels, Water Quality, and Floodplain Condition.

C. Resilience to Drought



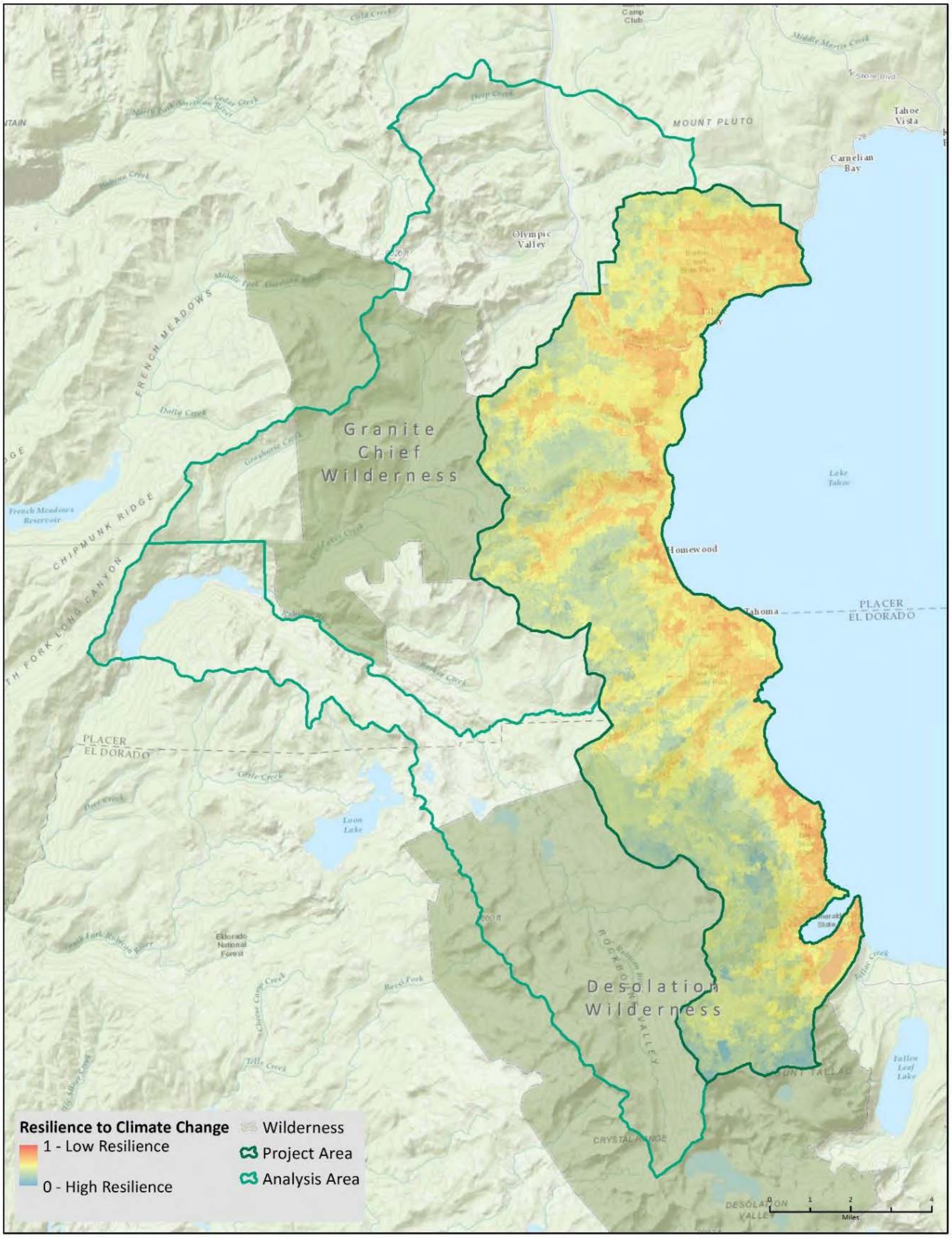
Composite C. Resilience to Drought composite indicator includes: Trees per Acre, Meadow Refugia, Meadow Connectivity, Climatic Water Deficit, Snowpack, Aquatic Organism Passage, Floodplain Condition, Bark Beetle Predators, Native Fish Diversity, and Seral Stage (Proportional). Note that the rank of Cascade Lake as least resilience is because a single indicator was evaluated for this lake, and therefore this reflects only this indicator and the lake should not be truly considered as least resilient.

D. Resilience to Insects & Disease



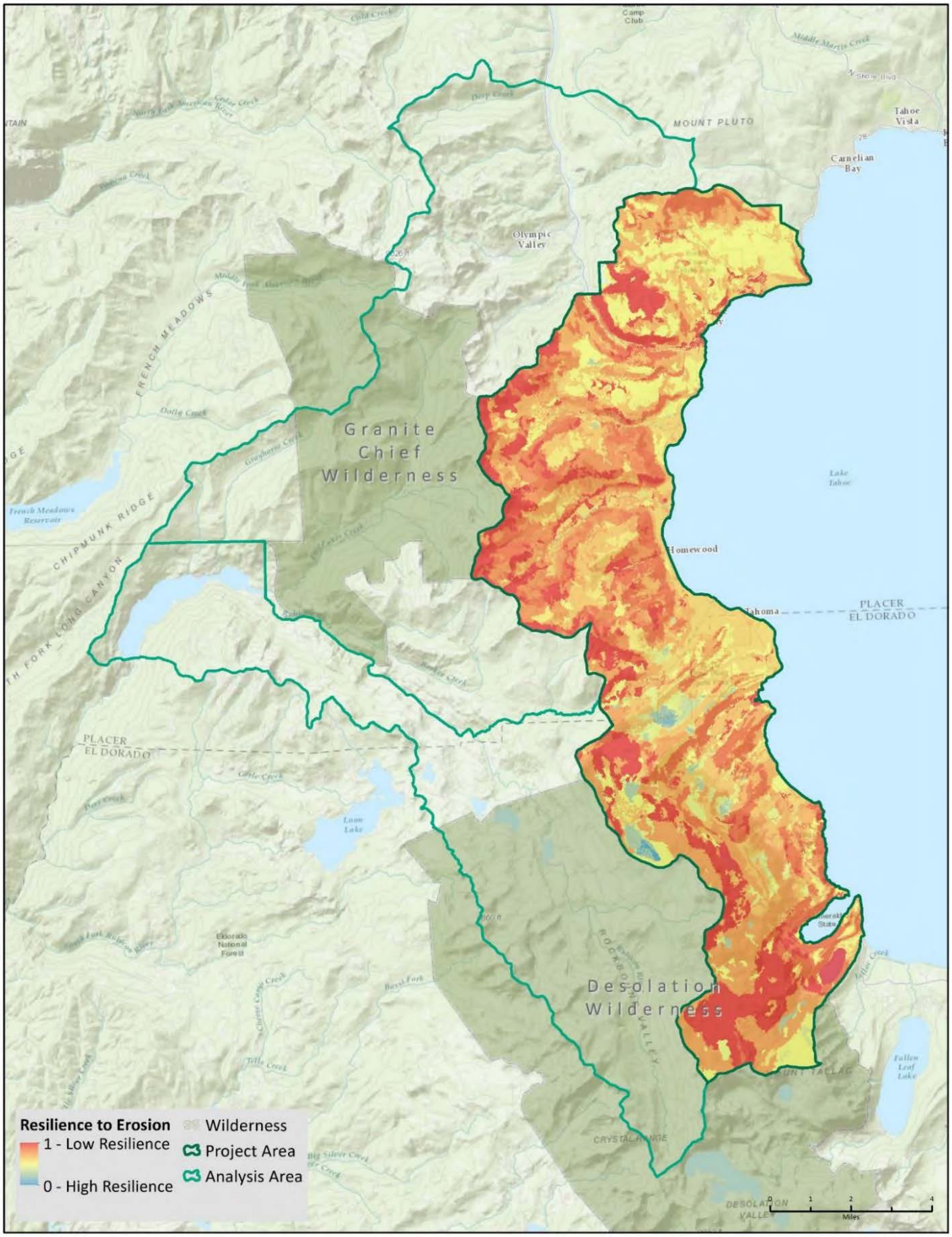
Composite D. Resilience to Insects & Disease composite indicator includes: Trees per Acre, Climatic Water Deficit, Bark Beetle Predators, and Seral Stage (Proportional).

E. Resilience to Climate Change



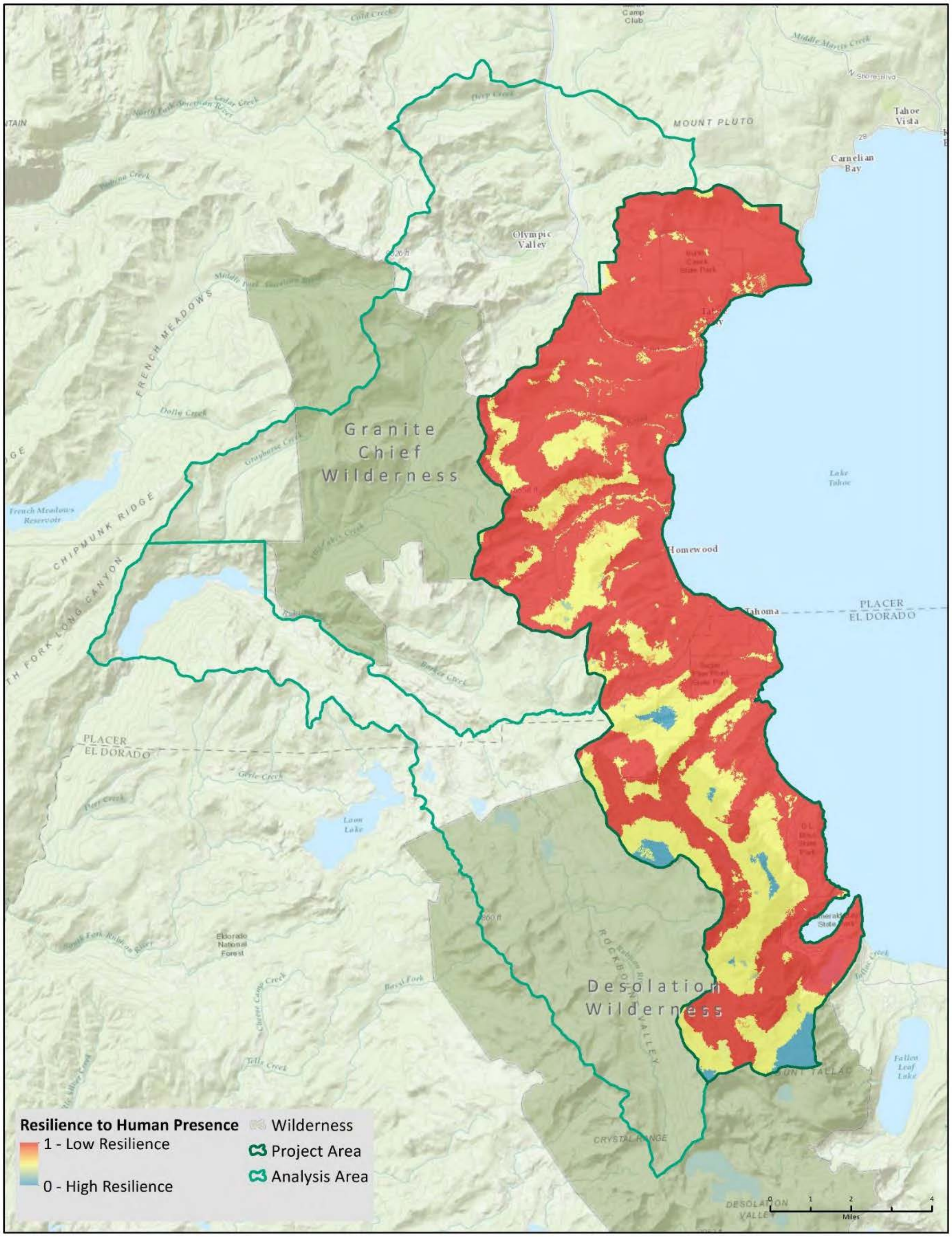
Composite E. Resilience to Climate Change composite indicator includes: Fire Severity, Trees per Acre, Meadow Refugia, Meadow Connectivity, Thermal Tolerance, Climatic Water Deficit, Snowpack, Human Access, Floodplain Condition, Bark Beetle Predators, Native Fish Diversity, and Seral Stage (Proportional). Note that rank of Cascade Lake as least resilient is because a single indicator was evaluated for this lake, and therefore this reflects only this indicator and this lake should not be considered as least-resilient.

F. Resilience to Erosion



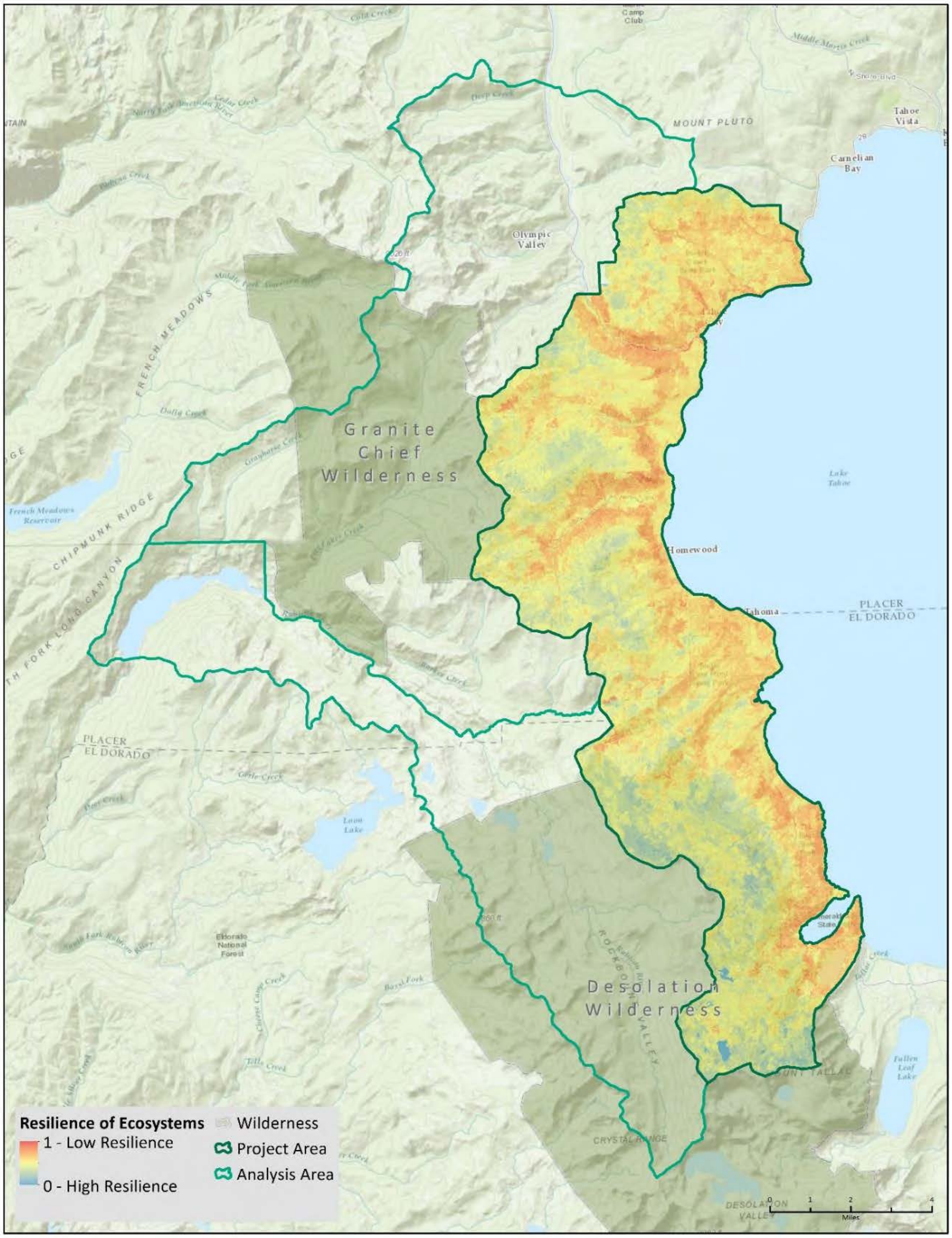
Composite F. Resilience to Erosion composite indicator includes: Roads and Trails Linked to Water Channels, Human Access, Water Quality, and Floodplain Condition.

G. Resilience to Human Presence



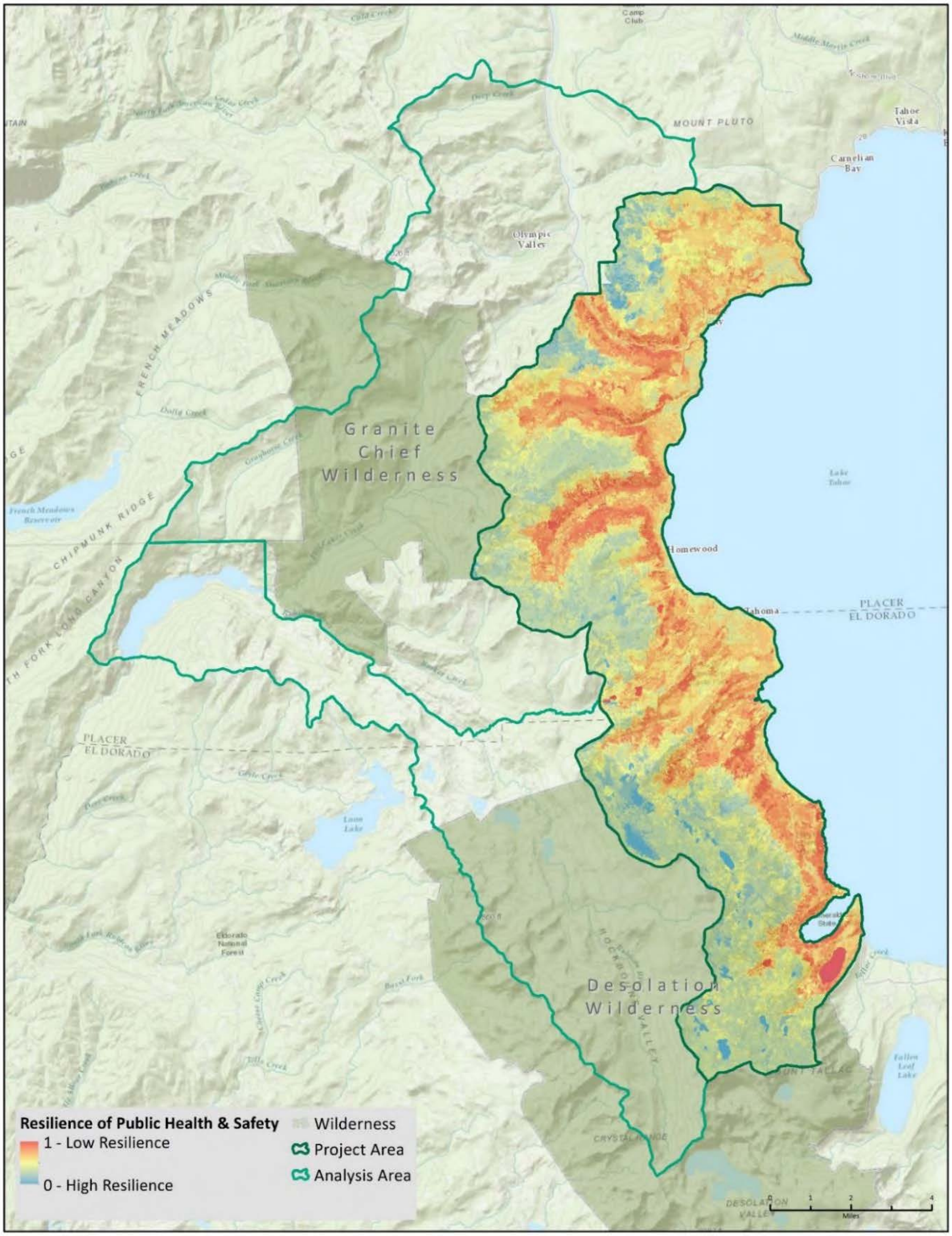
Composite G. Resilience to Human Presence & Activity composite indicator includes: Roads and Trails Linked to Water Channels, Human Access, and Floodplain Condition.

H. Resilience of Ecosystems



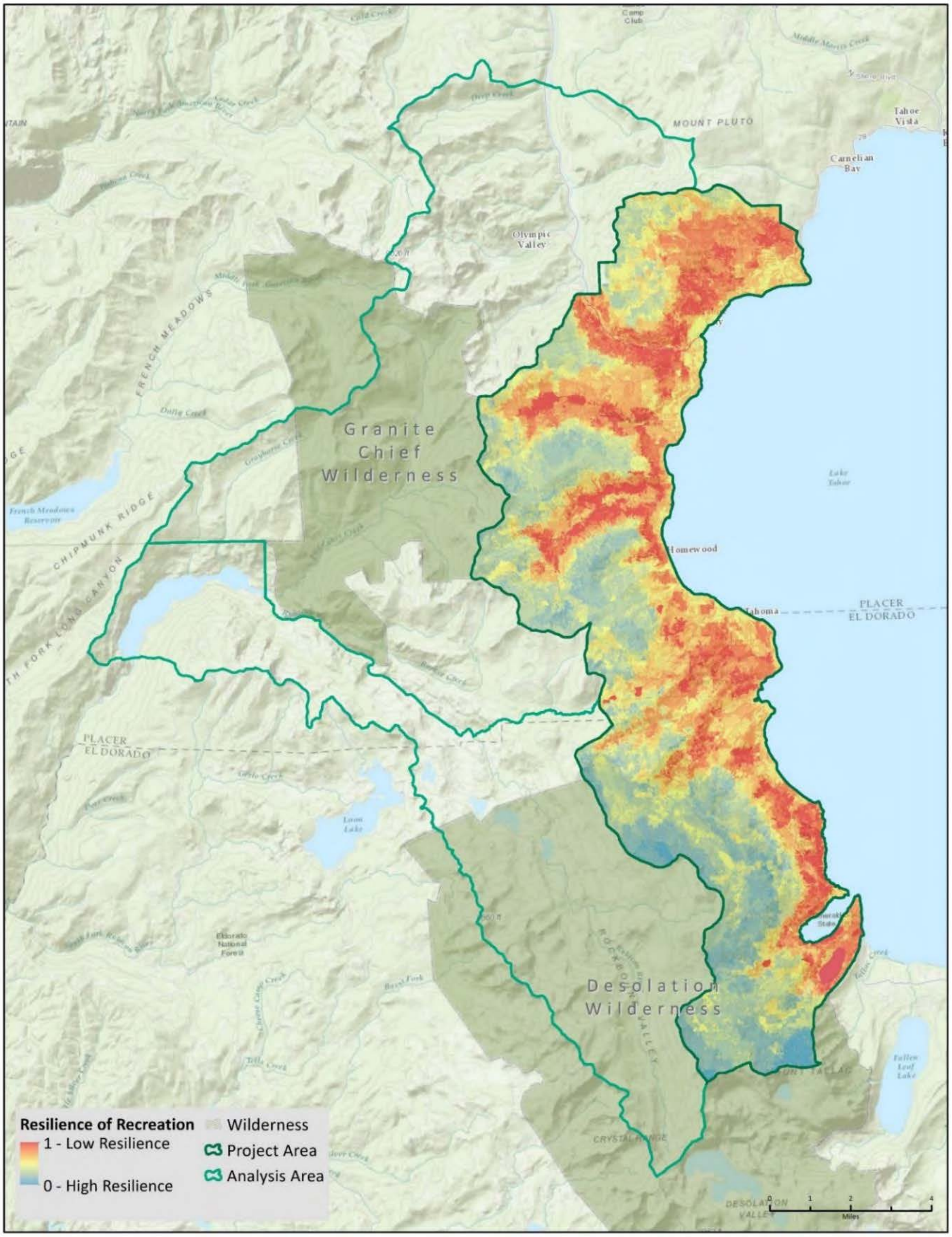
Composite H. Resilience of ecosystems composite indicator includes: Mean Condition Class, Fire Severity, Trees per Acre, Meadow Refugia, Meadow Connectivity, Thermal Tolerance, Climatic Water Deficit, Snowpack, Roads and Trails Linked to Water Channels, Human Access, Water Quality, Aquatic Organism Passage, Floodplain Condition, Bark Beetle Predators, Native Fish Diversity, Seral Stage (Proportional), Vertical Heterogeneity (Proportional), and Horizontal Heterogeneity (Proportional). Note that the rank of Cascade Lake as least resilient in this composite indicator is because a single indicator was evaluated for this lake, and therefore this reflects only this indicator and should not be cautiously considered as least-resilient.

I. Resilience of Public Health & Safety



Composite I. Resilience of Public Health & Safety composite indicator includes: Trees per Acre, Snowpack, Fire Risk Index, Roads and Trails Linked to Water Channels, Water Quality, and Floodplain Condition. Note that the rank of Cascade Lake as least resilient in this composite indicator is because a single indicator was evaluated for this lake, and therefore this reflects only this indicator and should not be cautiously considered as least-resilient.

J. Resilience of Recreation



Composite J. Resilience of Recreation composite indicator includes: Fire Severity, Trees per Acre, Snowpack, Fire Risk Index, Roads and Trails Linked to Water Channels, and Human Access. Note that the rank of Cascade Lake as least-resilient in this composite indicator is because a single indicator was evaluated for this lake, and therefore this reflects only this indicator and should not be cautiously considered as least-resilient.

Appendix C - Values-Disturbances-Indicators Table - December 1, 2017 Version

Lake Tahoe West Restoration Partnership - Landscape Resilience Assessment

A primary disturbance refers to a substantial event or process that drives the maintenance or alteration of ecosystem dynamics throughout large portions of the west shore social-ecological landscape.

* **"Wildlife"** signifies terrestrial and aquatic plants and animals, including fish. (P) indicates proportional indicator which was not summed equally (O) indicates overlay which is not part of aggregate (R) indicates a removed indicator that will be relevant when developed.

	LANDSCAPE VALUES & SERVICES - *WHAT WE WANT TO BE RESILIENT*											
	Upland Ecosystems including vegetation, wildlife*, water quality (lake clarity), water supply, soils, and carbon	**Meadow / Riparian Ecosystems** including vegetation, wildlife, water quality (lake clarity), water supply, soils, and carbon			**Aquatic Ecosystems** incl. wildlife, water quality (lake clarity), water supply	**Public Health and Safety**			**Cultural Landscapes** includes ecosystems, archaeological sites, as well as associations with places	**Recreation** Including Winter as well as Summer	**Composite Indicators** - Measure of resilience to individual disturbance (note: does not incorporate indicators labeled as (O) or (R))	**# of Indicators included**
DISTURBANCE TYPE - *WHAT WE WANT VALUES & SERVICES TO BE RESILIENT TO*	**Forests** **including shrub communities**	**Meadows and Marshes**	**Aspen Forests**	**Riparian Areas**	**Streams and Lakes**	**Life and Property**	**Water Quality and Supply** (municipal use, fire-fighting)	**Air Quality**				
A. Fire, including fire-related smoke ***affects the following values:*** *vegetation, wildlife, water quality (lake clarity), soils and carbon, as well life & property, water quality & supply, air quality, and recreation*	Mean condition class Fire severity Trees per acre Seral stage (P) Vertical & Horizontal heterogeneity (P) Vegetation type (O) Treatment type (O) (R) Terrestrial wildlife connectivity	Mean condition class Fire severity Roads & trails linked to water channels Human access	Mean condition class Fire severity Trees per acre (desire primarily aspen)	Fire severity Trees per acre Seral stage (P)	Not primary disturbance for the above value	Fire risk index	Fire risk index Water quality	(R) Air quality	*to be developed with the Washoe Tribe*	Fire severity Fire risk (R) Air quality	**Resilience to Fire:** Mean condition class; Fire Severity; Trees per acre; Fire risk index; Roads & trails linked to water channels; Human access; Water quality; Seral stage (P); Vertical Heterogeneity (P); Horizontal heterogeneity (P)	10
B. Flood *affects vegetation, wildlife, water quality (lake clarity), water supply, soils, carbon, life & property, water quality & supply, and recreation*	Not primary disturbance for the above value	Roads & trails linked to water channels Floodplain condition	Not primary disturbance for the above value	Roads & trails linked to water channels Floodplain condition (R) Stream channel stability	Floodplain condition (R) Stream channel stability	Roads & trails linked to water channels Floodplain condition	Water quality Floodplain condition	Not primary disturbance for the above value	*to be developed with the Washoe Tribe*	Roads & trails linked to water channels	**Resilience to Flood:** Roads & trails linked to water channels; Water quality; Floodplain condition	3
C. Drought **(linked to Tree Mortality)** *affects vegetation, wildlife, water supply, water quality & supply, and recreation*	Trees per acre Climatic water deficit Snowpack Bark beetle predators Seral stage (P) Treatment type (O) (R) Terrestrial wildlife connectivity	Meadow refugia Meadow connectivity Climatic water deficit Snowpack Floodplain condition Vegetation type (O)	Trees per acre Snowpack Floodplain condition Vegetation type (O)	Trees per acre Snowpack Floodplain condition Vegetation type (O) (R) Stream channel stability (R) Stream complexity	Snowpack Floodplain condition Aquatic organism passage Native fish diversity (R) Stream channel stability (R) Stream temperature	Not primary disturbance for the above value	Snowpack	Not primary disturbance for the above value	*to be developed with the Washoe Tribe*	Snowpack	**Resilience to Drought:** Trees per acre; Meadow refugia; Meadow connectivity; Climatic water deficit; Snowpack; Aquatic organism passage; Floodplain condition; Bark beetle predators; Native fish diversity; Seral stage (P)	10
D. Insects and Disease **(linked to Tree Mortality)** *affects vegetation, life & property, and recreation*	Trees per acre Climatic water deficit Bark beetle predators Seral stage (P) Treatment type (O) Vegetation types (O) (R) Terrestrial wildlife connectivity	Not primary disturbance for the above value	Trees per acre Climatic water deficit Seral stage (P)	Trees per acre Climatic water deficit Seral stage (P)	Not primary disturbance for the above value	Trees per acre (large amt. of hazard trees)	Not primary disturbance for the above value	Not primary disturbance for the above value	*to be developed with the Washoe Tribe*	Trees per acre (large amt. of hazard trees)	**Resilience to Insects and Disease:** Trees per acre; Climatic water deficit; Bark beetle predators; Seral stage (P)	4
E. Climate Change (other than A,B,C, so warming temperatures and changes in the timing and form of precipitation) *affects vegetation, wildlife, and recreation*	Fire severity Trees per acre Thermal tolerance Climatic water deficit Snowpack Bark beetle predators Seral stage (P) Treatment type (O) Vegetation type (O) (R) Terrestrial wildlife connectivity	Meadow refugia Meadow connectivity Thermal tolerance Climatic water deficit Snowpack Floodplain condition	Thermal tolerance Snowpack Floodplain condition	Thermal tolerance Snowpack Floodplain condition (R) Stream channel stability (R) Stream complexity	Snowpack Floodplain condition Native fish diversity (R) Stream channel stability (R) Stream complexity (R) Stream temperature	Not primary disturbance for the above value	Not primary disturbance for the above value	Not primary disturbance for the above value	*to be developed with the Washoe Tribe*	Human access (R) Air quality	**Resilience to Climate Change:** Fire severity; Trees per acre; Meadow refugia; Meadow connectivity; Thermal tolerance; Climatic water deficit; Snowpack; Human access; Floodplain condition; Bark beetle predators; Native fish diversity; Seral stage (P)	12
F. Erosion (other than B, so improperly engineered or maintained roads & trails, and mechanical vegetation treatments**)** *affects water quality (lake clarity), soils, carbon, and recreation*	Water quality	Roads & trails linked to water channels Human access Floodplain condition	Not primary disturbance for the above value	Roads & trails linked to water channels Human access Floodplain condition	Roads & trails linked to water channels Human access	Not primary disturbance for the above value	Not primary disturbance for the above value	Not primary disturbance for the above value	*to be developed with the Washoe Tribe*	Roads & trails linked to water channels Human access	**Resilience to Erosion:** Roads & trails linked to water courses; Human access; Water quality; Floodplain condition	4
G. Air Pollution other than A (e.g., ozone) *affects vegetation, air quality, and recreation*	*No current indicator, needs future investigation*	Not primary disturbance for the above value	Not primary disturbance for the above value	Not primary disturbance for the above value	Not primary disturbance for the above value	Not primary disturbance for the above value	Not primary disturbance for the above value	*No current indicator, needs future investigation*	*to be developed with the Washoe Tribe*	*No current indicator, needs future investigation*	**Resilience to Air Pollution:** TBD	TBD
H. Human Presence and Activity (other than A and F, so noise, vegetation manipulation, & invasive species) *affects wildlife and vegetation*	Human access (R) Terrestrial wildlife connectivity	Human access Floodplain condition	Human access Floodplain condition	Human access Floodplain condition	Roads & trails linked to water channels Human access	Not primary disturbance for the above value	Not primary disturbance for the above value	Not primary disturbance for the above value	*to be developed with the Washoe Tribe*	Not primary disturbance for the above value	**Resilience to Human Presence:** Roads & trails linked to water channels; Human access; Floodplain condition	3
I. Built Environment as it affects entire suites of management objectives and activities	*Will be threaded throughout the acceptable resilient conditions for relevant indicators (e.g., fire risk, water quality), and Wildland Urban Interface Defense Zone will possibly constitute an "overlay" in that regard.* *Will also be focus of finer-scale analysis during Phases 2 and 3 (Landscape Restoration Strategy, Restoration Project Planning).*											
Composite Indicators - Measure of landscape value/service resilience (note does not incorporate indicators labeled as (O) or (R))	**Resilience of Ecosystem:** Mean condition class; Fire severity; Trees per acre; Meadow refugia; Meadow connectivity; Thermal tolerance; Climatic water deficit; Snowpack; Roads & trails linked to water channels; Human access; Water quality; Aquatic organism passage; Floodplain condition; Bark beetle predators; Native fish diversity; Seral stage (P); Vertical heterogeneity (P); Horizontal heterogeneity (P)					**Resilience of Public Health and Safety:** Trees per acre; Snowpack; Fire risk index; Roads & trails linked to water channels; Water quality; Floodplain condition			TBD	**Resilience of Recreation:** Fire severity; Trees per acre; Snowpack; Fire risk index; Roads & trails linked to water channels; Human access		
# of Indicators Included	18					6			TBD	6		

Appendix D –Removed Indicators

Contents

This appendix describes indicators that were removed from Version 1 of the Landscape Resilience Assessment (LRA). Some will remain as removed indicators in future versions of the LRA due to a lack of data. Others may be refined and added into a future version of the LRA as additional data become available.

1. Air Quality

Version 1 (Original)

Fuel treatments reduce the risk of high intensity fire, but also present tradeoffs in regards to smoke production (prescribed or managed fire) and wind-borne particle movement (fire and non-fire). Landscape-scale forest treatment may reduce the extent of harmful downwind smoke from wildfire and the Lake Tahoe Basin may not currently be resilient to potential wildfire induced smoke impacts (Stevens et al., 2016). Forest thinning could also amplify wind erosion and dust flux comparable to wildfire without consideration of potential soil stability impacts (Whicker at al., 2006). Management under LTW intends to reduce $PM_{2.5}$ emissions in comparison to more extreme fire events expected in the absence of LTW management. Education and communication will be essential to convey the importance and intention of fire management to residents and visitors that experience smoke generated from management actions.

PM 2.5 Desired Condition – TRPA Adopted standard based on Federal 3-year average of the 98th percentile 24-hour $PM_{2.5}$ concentration at any monitoring station not to exceed 35 mg/m^3.

PM 2.5 Exceedances threshold - tracking days above federal thresholds due to forest burning for monitored locations within the Tahoe Basin and in Reno. Days of Air Quality Index Exceedances that are:

1) unhealthy for sensitive (35 ug/m3),
2) unhealthy for all (56 ug/m3),
3) very unhealthy for all (150 ug/m3) or
4) hazardous (250 ug/m3)

Note: This is a general, landscape-scale indicator, but we believe that there will be opportunities to do local and fine scale air monitoring as technologies improve. Focused field research on $PM_{2.5}$ contributions from large, planned prescribed burns will be helpful for model verification.

Version 2 (Current)

The original intent of this indicator was to produce a spatially explicit evaluation of the current state of air quality resilience similar to other resilience indicators. However, air quality data are not sufficiently distributed spatially or temporally to produce a robust resilience indicator at this time. As we proceed with the Landscape Restoration Strategy in Phase 2 of Lake Tahoe West (LTW), air quality will be quantitatively assessed as $PM_{2.5}$ concentrations (and perhaps other pollutants) in tradeoffs analyses. This information will be very valuable as Phase 2 proceeds since it identifies some current sources of information that may highlight gaps, or may be improved upon.

Smoke in the Lake Tahoe Basin (LTB) communities is inevitable from wildfires; at some point in time, a wildfire will occur inside or outside the LTB, and smoke will impact the Basin. The LTW restoration efforts will be designed to achieve conditions that are more resilient to large and intense wildfires that emit very large amounts of smoke. But these efforts will require use of managed wildfire and prescribed fire that also will result in smoke impacts. However, smoke impacts from management application of fire will result in lower smoke impacts since these activities will be implemented under conditions when fire intensities are more moderate and smoke dispersion conditions are more favorable. Below we characterize the current state of community resilience to smoke-related air quality impacts as part of the LRA. During Phase 2, the LRS, tradeoffs between (TBD) potential landscape restoration strategies will be evaluated using more robust quantifiable air quality indicators. During the LRS process, the information below will help inform strategies that will enhance or improve community resilience while the work to increase forest and ecosystem resilience proceeds.

Community resilience to degraded air quality depends not only on sources, concentrations, and durations of pollutants, but also on the communities' ability to respond to events in a manner that minimizes the impacts. In terms of smoke from wildfires and prescribed fires, there are a variety of information sources available to assist with planning for, and responding to, smoke events. The list of examples below is arranged from local to federal, and is not an exhaustive list. It is unlikely members of the public are aware of all these sources of information, thus this is not considered a robust measure of community resilience.

This social indicator for air quality is framed around two concepts:

1. The distribution and density of smoke and health information networks including doctors and health care providers, websites and other readily available fire, smoke, and health information, and local coordinated programs that address the issue e.g. TFFT.
2. Interagency coordination about smoke issues related to wildfire and prescribed fire activities.
    - The Lake Tahoe Basin land management, fire protection, and regulatory agencies, have coordinated community protection efforts into the Tahoe Fire and Fuel Team (TFFT, http://tahoe.livingwithfire.info/tahoe-fire-fuels-team). The website provides a map of any ongoing prescribed fires. The Fire Public Information Team (Fire PIT) issues press releases regularly to inform the public of details about upcoming planned prescribed fires.
    - Prior to igniting prescribed fires, implementing agencies in the LTB notify smoke-sensitive individuals by phone in the areas that may be impacted by smoke. Contact TFFT if you would like to be added to the notification list.
    - Medical providers are another currently existing information network that could efficiently disseminate air quality related information. Since medical service know which of their patients are most at risk to smoke-related complications they are in the ideal positions for targeted notifications. Particularly with the broad availability of cell phones and social media. At this point we don't have any information on whether this avenue is currently being exploited.
    - The National Weather Service issues public smoke advisories when impacts are expected.
    - The Air Fire air quality monitoring site provides near-real-time (up to past hour) and past 7 days PM2.5 records for many air quality monitors sited throughout the US (https://tools.airfire.org/monitoring/v3/#/?date=LATEST&productType=plotTable&userProfile=simple). Zoom in on the map to the area of interest and point and click on a monitor to view graphics of the last 7 days, hourly and 3-hour average PM2.5 observations (Fig 1).

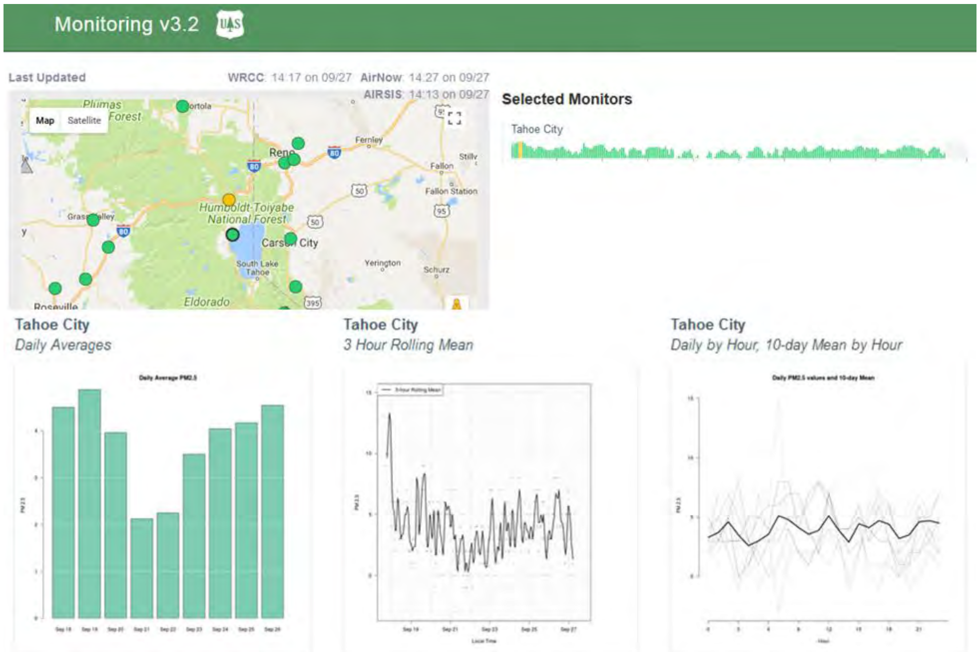


Figure 1. Airfire monitoring page. Map zoomed in to Norther Sierra Nevada area. Monitor selected is Tahoe City. Graphics show PM2.5 concentrations (ug/m3) for (left to right) 24-hour average for last 7 days, 3-hour rolling mean, and daily by hour (gray lines) and 10-day hourly mean (black line).

- County air districts and public health departments provide a great deal of smoke related information on their websites. For Placer County, see:
  - http://www.placerair.org/
  - http://www.sparetheair.com/ (Fig 2)

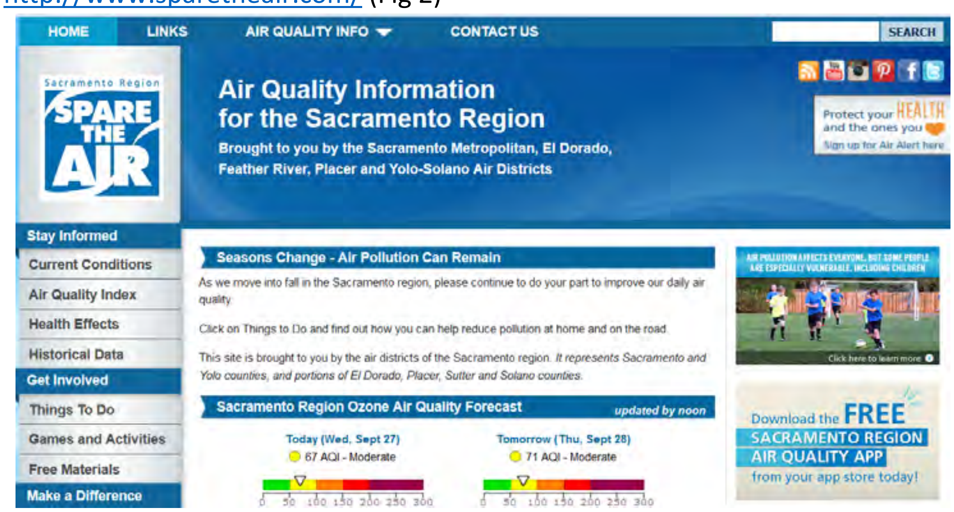


Figure 2. Placer Counties "Spare the Air" website.

- El Dorado County Air District's Facebook Page: https://www.facebook.com/EDCAQMD/
- During large wildfires, Air Resource Advisors are often deployed to provide smoke forecasting and other information to cooperators and the public. The program is National in scope. See https://wildlandfiresmoke.net/. Figure 3 shows a portion of a smoke forecast outlook issued for wildfires in the Central Sierra during the 2017 fire season.

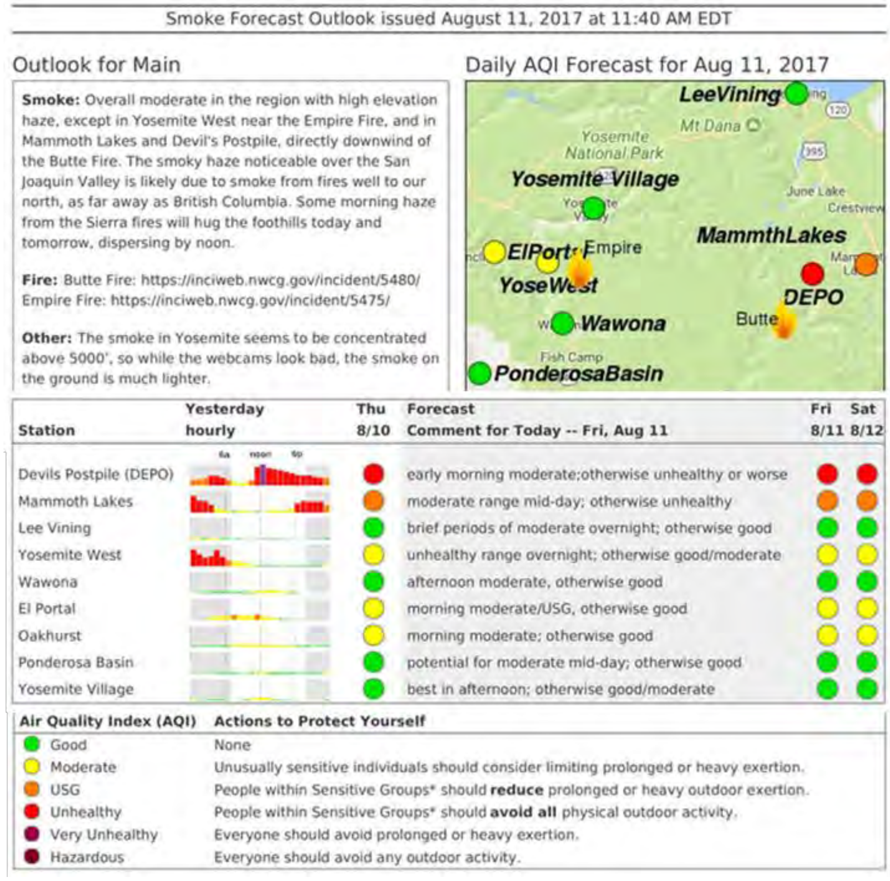


Figure 3. Smoke Forecast Outlook issued for 2017 Central Sierra wildfires.

- The Center for Disease Control (CDC) provides health information and guidance regarding wildfire smoke at https://www.cdc.gov/features/wildfires/index.html.
- As does the US Environmental Protection Agency (EPA) at https://www.airnow.gov/index.cfm?action=airnow.local_city&cityid=286, (Fig. 4), as well as a Citizen-Science intended to increase understanding of how smoke exposure affects health and productivity, and to establish communication strategies that protect public health during smoky days. See https://www.epa.gov/air-research/smoke-sense-study-citizen-science-project-using-mobile-app
- California Air Resources Board provides an online tracking and information system called Prescribed Fire Information Reporting System (PFIRS, Fig 4): https://ssl.arb.ca.gov/pfirs/.

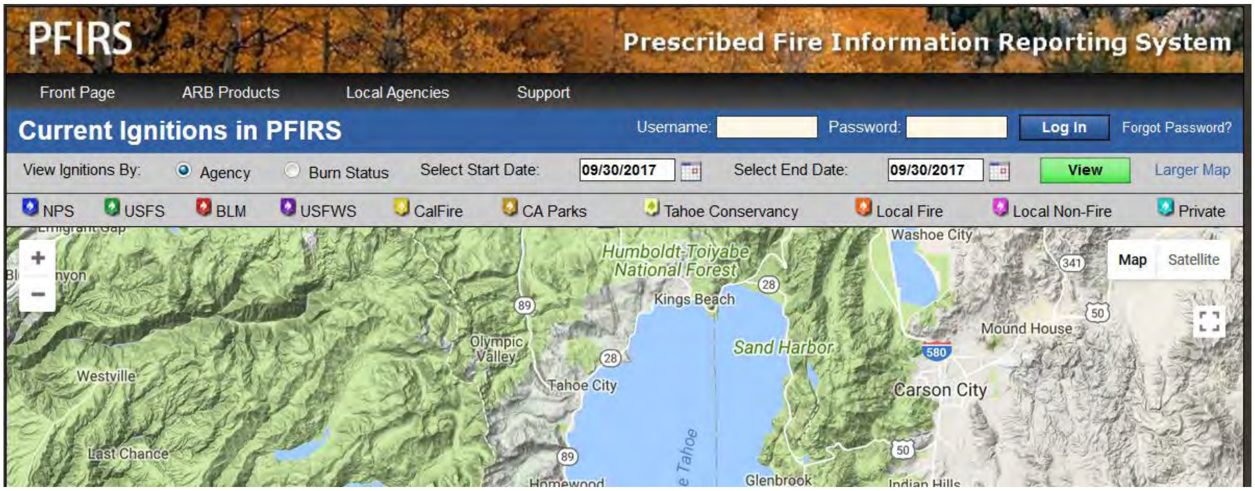


Figure 4. Prescribed Fire Information Reporting System

- In California, daily smoke conference calls are held at 1300. These calls facilitate coordination between agricultural burners, agencies implementing prescribed fires and wildfire incident management, air districts, California Air Resource Board, and Geographic Area Coordination Centers (GACCs). During these calls meteorologist discuss current and forecasted weather and smoke dispersion potential. Burners and fire mangers then discuss the status of their projects and plans for the day.

2. Understory Vegetation Structure and Composition

The structure and composition of understory vegetation is linked to several indicators of resilience, including probable fire behavior/severity and the presence of key wildlife habitat components. Understory vegetation characteristics are currently incorporated into several indicators, including: Fire Severity and Fire Risk Index through fuel models; Mean Condition Class by incorporation of fuel treatments; Vegetation Composition and Structure through seral stage; and Diversity of Ecotypes through existing vegetation cover type.

Data planned for acquisition include terrestrial laser scanning plots which will improve the capability of understory structure measurements when combined with Aerial LiDAR and hyperspectral imagery, which will provide more direct measures of understory composition than are currently available.

Data source: TLS, Hyperspectral Imagery, FIA (limited)

3. Soil Health

The LTW Interagency Design Team (IADT) recognizes the importance of soils in resilient landscapes. However, soils are such a slow variable, and at the landscape scale of the LRA the IADT felt soil health was adequately covered under Upland and Meadow/Riparian Ecosystems. The resilience of those ecosystems, though focused on vegetation dynamics for the LRA, are integrally connected to soil health. Soils will be captured in upcoming analysis and LTW products. Roads, Trails and Bare Soil are also being addressed to capture soils erosion and delivery to streams.

After conversations with soil scientists Toby O'Geen (UC Davis) and Matt Busse (US Forest service) regarding soil health at the landscape scale, they agreed it is not practical to measure chemical or biological indicators, and the best management practice for soils is to avoid erosion and keep soil in place and covered. However, due to past management and fire suppression, many areas likely have organic matter accumulations that exceed historic levels. Reintroduction of fire onto the landscape will help to remedy this over accumulation of organic matter and is important to consider during development of implementation strategies.

As the planning process moves closer to implementation, soils will be more specifically addressed as there are clearly soil capability issues that will emerge, such as operability of mechanized equipment on steep slopes. The *Soil Survey of the Tahoe Basin Area, California and Nevada* has a wealth of information on the soils in the Tahoe Basin and will be a valued source of information as the process moves forward. It has been discussed with GIS staff the desire to "burn" the Soil Survey data into EcObject for future analysis.

4. Species Composition for Trees per Acre

Originally the Trees per Acre indicator had number of species associated it. This is a critical element to assess because the greater the diversity of species of trees, the greater potential for resilience, especially resilience related to climate and insects/diseases. However, we currently do not have data for species composition. The best available vegetation data we have is from Eveg and that data set only has regional dominance type for each EcObject, not the suite of species that exist in the stand. Aerial-based LiDAR does not provide species identity either.

With regard to further future development, in order to assess this indicator, which would be important, hyperspectral imagery would be of use. Even if we cannot get to species level, the knowledge that a stand is comprised of multiple species rather than just one is important. Also important is knowing the ratio of species within a stand, which hyperspectral imagery would allow at the minimum to a genera level.

Below is a summary of the literature for species composition in stands similar to those in the LTB. These data could be built upon if this indicator is moved forward.

Jeffrey Pine Forest Species Composition

Tree Species Composition[1]	Source	Location	Notes
Jeffrey pine - mean 22 (79%) (range 10-36) White fir – mean 5 (18%) (range 0-13) Red fir – mean 0.4 (<5%) (range 0-4)	Taylor 2004 and Taylor et al. 2014	Lake Tahoe Basin (east shore)	≥10cm dbh
Jeffrey pine 22% Sugar pine 27% White fir 34% Red fir 3% Incense cedar 15%	North et al. 2007	Teakettle (Sierra NF)	≥5cm dbh
Incense cedar 36% Jeffrey or Ponderosa pine 23% White fir 16% Sugar pine 11% Douglas fir (<5%)	Scholl and Taylor 2010	Yosemite NP	≥10cm dbh Having a hard time finding ref

Tree Species Composition[1]	Source	Location	Notes
Jeffrey or Ponderosa 43% Incense cedar 34% White fir 13% Sugar pine 7% Douglas fir <5%	USDA 1911 from Safford 2013		≥15.2cm dbh
Black oak 58% Ponderosa pine 32% White fir, incense cedar, and sugar pine total = 10% Incense cedar 42% White fir 42% Sugar pine 16%	Parsons and Debenedetti 1979	Sequoia and Kings Canyon NPs	No Jeffrey pine, lower elevation, oaks present ≥12cm dbh.
At the stand scale, the proportion of Jeffrey pine to shade tolerant trees (white fir, red fir, incense cedar) is at least 3:1. In moist Jeffrey pine sites, proportion of Jeffrey pine to shade tolerant species (e.g., lodgepole pine, incense cedar) may be less.	LTBMU Forest Plan 2016		Desired conditions for JP forest composition for all Forest
25% yellow pine, 1% sugar pine, 25% doug fir, 44% white fir, and 5% incense cedar.	Leiberg (1902) from Safford 2013	North Lake Tahoe, Plumas, Tahoe NF	Study area heavily cut. Leiberg estimated that white fir was about 25-40% of uncut stands of yellow pine.
Yellow pine most abundant tree in the YPMC belt, followed by white fir, then incense cedar, sugar pine, and Jeffrey pine. Yellow pine most common on south, west, and east aspects. Typical ranges of species mixtures: 50% yellow pine, 30-45% white fir, 20-30% incense cedar, 5-20% sugar pine (pg 78 of Safford 2013).	Sudworth (1900) from Safford 2013	South Lake Tahoe, El Dorado, and northern portions of HT and Stanislaus	Note that Stephens 2000 refers to this as mixed conifer type. Stephens 2000 notes that there is one pure Jeffrey pine forest type in Sudworth's notes that he doesn't analyze because there is no replicate.
[1] Most percentages estimated from Figure 23 in Safford 2013 (NRV for Yellow pine)			

White fir- mixed conifer Species Composition

Tree Species Composition	Source	Location	Notes
White fir mean-27 (range 6-58) Red fir mean 5 (range 0-23) Incense cedar mean 2 (range 0-12)	Taylor et al. 2014	Sugar Pine Point State	NOTE: Safford 2013 classifies this as yellow pine in the NRV

Tree Species Composition	Source	Location	Notes
Lodgepole pine 0.1 (range 0-0.8) Jeffrey pine mean 18 (range 5-42) Sugar pine 1 (range 0-6) Western white pine0.8 (range 0-6) (white fir in the 1873 forest outnumbered Jeffrey pine by 1.5:1 – almost half of all white fir measured were smaller than 25 cm dbh, and Jeffrey pine was the dominant tree in the larger size classes. – per Safford 2013 assessment of this study).		Park, Lake Tahoe	paper but Taylor et al. 2014 classify as mixed conifer. 12 sites; ≥5cm dbh mixed conifer forests may be co-dominated by incense cedar, sugar pine, Jeffrey pine, red fir, western white pine, or white fir – compares to other estimates that are actually provided above as yellow pine forests.
Dominated by white fir with Jeffrey pine, sugar pine, red fir, and incense cedar as important associates. S=At the stand scale, the proportion of white fir to shade intolerant pines (e.g., Jeffrey, sugar) varies from about 1:1 on drier and warmer sites to 2:1 or greater in moist and/or high productivity sites.	LTBMU Forest Plan 2016		Desired conditions for white fir – mixed conifer forest composition for all Forest

Red fir Species Composition

Tree Species Composition	Source	Location	Notes
58% of trees red fir White fir mean – none provided Red fir mean – 38 (range 28-57) Lodgepole pine mean – 6 (range 0-23) Jeffrey pine mean – none provided Western white pine mean – 21 (range 9-30)	Taylor 2004 and Taylor et al. 2014	Lake Tahoe, east shore	≥5cm dbh
Dominated by red fir with white fir and Jeffrey pine as important associates at lower elevations, and western white pine, lodgepole pine, and Jeffrey pine at higher elevations.	LTBMU Forest Plan 2016		Desired condition for red fir on all Forest lands
Red fir – 110 (63%) Jeffrey pine – 10 (6%) western white pine – 12 (7%) lodgepole pine -28 (16%) mountain hemlock -14 (8%)	Stephens 2000 using data from Sudworth 1899 field notebooks	Southern portions of Tahoe NF and El Dorado NF, northern portion of Stanislaus	Trees greater than 28cm

Tree Species Composition	Source	Location	Notes
		(and Safford 2013 says SLT too?)	
Red fir - 80.5 trees/ac (70%)	Meyer NRV		Sources used in Meyer calculation include: Bekker and Taylor 2001, Taylor and Solem 2001, van Wagtendonk 1985, Miller et al. 2012, Mallek et al. in review

Aspen Species Composition

Depending on location, elevation, and site characteristics, a number of conifer species may be present (up to 25% canopy cover), and other hardwoods like alder or willow may occur nearby (LTBMU Forest Plan 2016). In aspen stands, aspen dominate the overstory, with conifers comprising <25% of the canopy. Aspen comprise more than 75% of the overstory (LTBMU Forest Plan 2016). The goal is also to have an aspen stand with ≥ 60% aspen represented (Berrill and Dagley).

5. Shrubs for Trees per Acre

This indicator is specific to shrubs within forested stands and is not for climax shrub communities. This indicator is valuable because stands with low densities of trees will be most resilient to future disturbance when there is also a lower density of shrub cover. For example, if a stand has very high shrub cover then it would be less resilient to fire and drought because there would be more fuel (in case of fire) and more competition (in case of drought). Therefore, understanding shrubs per acre, particularly in combination with knowing trees per acre, can be very valuable to a resilience assessment.

The following was the acceptable condition we developed but this should be interpreted cautiously for forested systems because the shrub cover field was only calculated for shrub dominated ecosystems and not forested systems: <23% of shrub cover in forested ecosystems (note this is in forested stands, not openings or climax shrub communities). This acceptable resilient condition is based on the **Historic Range of Variability for Chaparral in the Sierra Nevada and Southern Cascades (HRV)** Becky Estes, Central Sierra Province Ecologist, Eldorado National Forest, Placerville, CA. The HRV states: "In a recent study, Lyderson and North (2012) documented varying degrees of chaparral cover in Yosemite and Sequoia/Kings Canyon National Park (Central bioregion) after 30 years of recurring fires. Higher cover of chaparral was common at ridge lines (23.1%) and upper slope positions (19.5%) while lower slopes had lower rates of cover (12.1%). There was no difference between Northeast facing slopes (17.8%) and Southwest facing slopes (16.3%). Similar patterns are evident in a number of studies documenting the occurrence of chaparral in areas where fire severity would be predicted to be high (Taylor and Skinner 1998, Beaty and Taylor 2001, Beaty and Taylor 2008). These observations may not apply to all circumstances, but they do support the management of forested and montane chaparral communities using topographic variability and likely fire severity, which is the underlying principles behind both GTR-200 and GTR-237 (North et al. 2009, North 2012)."

The IADT focused on this one section of the HRV document to develop the acceptable condition for forested stands, but note that this is not for climax communities. Based on these data the IADT identified a threshold of 23% shrub cover. When shrub cover increases above 23% then the stand would no longer be resilient (primarily to fire, but potentially also to drought). The data we have available with shrub cover from the HRV document with the LiDar has a cut off of 19.9 and then 29.9 therefore we identified 19.9 as highly resilient and the 29.9 cutoff as potentially resilient. In future phases of LTW, the IADT is interested in identifying a spatial data layer to support these methods.

The resiliency scale ranges from 0 to 1 with 0 having the greatest resilience. This scaling was used to provide for scaling up and combining multiple indicators to evaluate resilience. All other conditions with data will be given a resiliency rank of 0. 999 was used for no data.

Table 1. Resiliency scale and codes for shrubs per acre for forested types.

Shrub Cover	EcObject Codes SHB_CFA	All forested types*	All non-forest types
<20	00, 05, 15	0	999
20:29.9	25	0.5	999
≥30	35, 45, 55, 65, 75, 85, 95, x	1	999
*see table 2 below for determination of which WHR types were included as forested.			

Table 2. WHR vegetation type from VTM data – General vegetation type crosswalk.

General	WHR	Include as Forested Type for Shrub cutoffs
Aspen	Aspen – ASP	No
Herbaceous	Annual Grassland – AGS	No
	Wet Meadow – WTM	No
Mixed Conifer	Lodgepole Pine – LPN	Yes
	Montane Hardwood - MHW	Yes
	Montane Hardwood-Conifer - MHC	Yes
	Sierran Mixed Conifer- SMC	Yes
	White Fir – WFR	Yes
None	Barren – BAR	No
	Lacustrine – LAC	No
	Unknown	No
	Urban – URB	No
Red Fir	Red Fir - RFR	Yes
Riparian	Montane Riparian - MRI	No
Shrub	Bitterbrush - BBR	No
	Desert Scrub - DSC	No
	Montane Chaparral - MCP	No
	Sagebrush - SGB	No
Subalpine	Subalpine Conifer - SCN	Yes
Yellow Pine	Eastside Pine - EPN	Yes
	Jeffrey Pine - JPN	Yes
	Ponderosa Pine - PPN	Yes

*Note we did not include aspen as a forested type because we would expect that in some cases there may be a high cover of willow or alder that may be considered shrubs and this is analysis is really focused on chaparral

Literature Used

Lyderson, J. and M. North. 2012. Topographic variation in structure of mixed-conifer forests under an active-fire regime. Ecosystem **15**:1134-1146.

Taylor, A. H. and C. N. Skinner. 1998. Fire history and landscape dynamics in a late-successional reserve, Klamath Mountains, California, USA. Forest Ecology and Management **11**:285-301.

Beaty, R. M. and A. H. Taylor. 2001. Spatial and temporal variation of fire regimes in a mixed conifer forest landscape, Southern Cascades, California, USA. Journal of Biogeography **28**:955-966.

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6. Carbon

The IADT recognizes the importance of carbon storage and sequestration in resilient landscapes. Although California forests are currently functioning as a carbon sink, it's unclear whether current stand densities and resulting carbon stocks are sustainable in the face of fire, insects, disease, and other disturbances. This makes it difficult to focus on total carbon stock as an indicator, as it is more than likely that forest carbon stocks may need to decrease to increase overall forest resilience to disturbance.

Focusing on the ratio of carbon in live pools versus dead pools may be adequate for measuring the resilience of the forest carbon sink, but this requires extensive data collection. The U.S. Forest Service Forest Inventory and Analysis Program (FIA) has extensive plot data to measure forest carbon stocks, however it is difficult to downscale these data to match the scale of LTW. Additionally, post-treatment data collection is required to determine treatment effects on carbon stocks, which is costly and time-consuming. While the FIA Program may eventually collect these data in treatment areas, the LTW's need for these data may not match the FIA data collection cycle.

Focusing on carbon sequestration rates is another metric that could be used. Treatments that result in increasing growth rates rather than decreasing growth rates by reducing competition could be beneficial, but this may not be an appropriate goal for late seral forests where growth rates naturally slow as trees mature.

It is also difficult to establish a desired condition for any of these metrics when we are just beginning to quantify forest carbon dynamics. Comparisons can be made to a baseline or no-action scenario, but it would be difficult to set a quantitative desired condition at this point.

Other considerations of carbon associated with forests includes carbon stored long-term in harvested wood products and emissions associated with burning wood with and without energy capture. This would require extensive harvest and use data that may not be available at the LTW scale.

Ultimately, while the IADT recognizes that maintaining forests as healthy, resilient carbon sinks is an important goal, it is currently difficult to develop quantitative goals for this indicator. As more information is developed on forest carbon in CA, it may be possible to develop quantitative metrics for a carbon indicator in the future. New information is still in development from the California Forest Carbon Plan, the California Assembly Bill 1504 Forest Ecosystem and Harvested Wood Product carbon inventory, the California Air Resources Board Natural and Working Land's carbon inventory, and the Sierra Nevada Meadows Partnership greenhouse gas flux studies.

Carbon sink resilience is integrally connected to vegetation dynamics for the Landscape Resilience Assessment. Strategies that result in overall forest and meadow ecosystem resilience should address carbon sink resilience.

As the planning process moves closer to implementation, carbon can be considered more specifically with different management scenarios.

7. Invasive Species

The intent of the IADT was to develop an indicator for the resilience of the West Shore landscape (pre- and post-treatment) to invasive species, both terrestrial and aquatic. The IADT recognize the role disturbance plays in the introduction and spread of invasive species, including fire (wild and prescribed), tree harvest activities, and recreation activities that may provide a vector for introductions and other ground disturbing activities. However, invasive species data is limited for both aquatic and terrestrial species. There are currently no known aquatic invasive plant species in west shore streams and no invasive terrestrial species currently exhibiting ecosystem altering effects, though cheat grass is a high concern.

As the LTW partnership proceeds towards implementation, a closer look at invasive species and the role they play in displacing native species (aquatic and terrestrial), altering fire behavior (plants), and changing desired natural processes will need to be addressed. Furthermore, during planning for implementation, best management practices will need to be put in place to prevent the introduction of new and the spread of current invasive species.

8. Wildlife: Upper Trophic

This indicator is being developed during the science modeling phase and will be included in a future version of the LRA. The modelling will be done by Keith Slauson of the USFS Pacific Southwest Research Station. Upper trophic predators for this indicator include the American marten, California spotted owl, and northern goshawk. The analysis would be based on habitat amount and type at three different spatial scales (stand, territory, landscape) and use data collected in the LTW project area.

Disproportionate declines in conifer species, as documented for pines in the Lake Tahoe Basin, without corresponding effects on primary seed predators can further accelerate already declining tree species representation (McKinney and Fiedler 2009). Upper trophic predators contribute to forest resilience by acting to provide top down control on seed foragers. Squirrels and other rodents can exert significant ecological and evolutionary pressure on seed quantity, community composition, and forest structure by directly influencing seed fate (Steele et al. 2005). Preference of pine seeds over fir seeds by seed harvesting small mammals could provide an advantage for fir species in mixed conifer systems (Lobo et al. 2009). Tamiasciurus squirrel (Douglas squirrel or chickaree) predation on sugar and Jeffrey pine can be intense enough that all cones that fall to the ground are consumed, such that germination is limited to wind dispersal (Benkman et al. 1984). High squirrel populations can also greatly suppress the opportunity for wind dispersal of seeds as Tamiasciurus squirrels harvested >80% of white pine cones by gnawing off branches and cone stems before the cones had a chance to open (Benkman et al. 1984). Seed predation on yellow pine in western forests can be so high that sufficient seed is available for new regeneration only once or twice per decade (Bailey et al. 2002). Upper trophic predators increase the incidence of unrecovered seedling cache germination, an important regeneration process in many tree species, by capturing prey; and also affect prey behavior as predator presence increases predator vigilance and reduces seed predation by rodents (Sunyer et al. 2013).

Upper trophic predators may also be important secondary dispersers of plant seeds by preying on seedeaters and moving viable seed that depends on animal dispersal much greater distances than primary dispersers such as mice, voles, and squirrels (Hamalainen et al. 2017). This diploendozoochory (seed dispersal that involves the ingestion of the seed by two or more separate species of animals in sequence) could be very important in facilitation of plant movement between remote populations or habitat fragments and in the ability of plants to adapt to changing climatic conditions that drive range shifts (Hamalainen et al. 2017). This long distance plant dispersal mechanism involving different types of predatory birds could play a much more important role than is currently understood (Nogales et al., 2012). Loss or decline in this potential dispersal mechanism could disrupt ecosystem function and reduce ecological resilience.

Acceptable Resilient Condition: Upper trophic predators would be likely to be supported and provide functional roles towards an acceptable resilient condition in the Lake Tahoe West study area if >40% of the landscape provides a functional strength of >65%. A measure of functional strength will quantify this threshold with a score of 0 meaning that none of the Upper Trophic Species are supported to a score of 1, where all three species are supported. The measure of functional strength across the landscape will be established through a composite analysis of habitat amount and type, distribution, and disturbance factors that would be suitable to sustain persistent populations of these top predators.

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Lobo, N., M. Duong, and J.S. Millar. 2009. Conifer-seed preferences of small mammals. Canadian Journal of Zoology 87(9):773-780.

McKinney, S.T. and C.E. Fiedler. 2009. Tree squirrel habitat selection and predispersal seed predation in a declining subalpine conifer. Oecologia

Nogales, M., R. Heleno, A. Traveset, P. Vargas. 2012. Evidence for overlooked mechanisms of long-distance seed dispersal to and between oceanic islands. New Phytologist 194:313-317.

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Lambert, P.E. Hulme, S.B. Vander Wall (Eds) Seed fate: predation, dispersal and seedling establishment. CABI, Wallingford, pp 205-221.

Sunyer, P., A. Munoz, R. Bonal, J.M. Espelta. The ecology of seed dispersal by small rodents: a role for predator and conspecific scents. Functional Ecology 27:1313-1321.

9. Aquatic Wildlife: Stream Temperature

Temperature is an indicator of a stream's resilience to climate change. Native species in the streams of Lake Tahoe are adapted to cold water conditions. Therefore, it is assumed that increased stream temperatures will make the habitat less suitable for native species to support life history requirements and increase the risk of warm water fish species infestations. Streams that have colder temperatures (in the optimal range for native trout reproduction and growth) will be more resilient to climate change. Maximum daily temperature is more ecologically relevant for aquatic organisms than average daily temperature as even brief daily exposure to higher temperatures can have significant effects on growth, reproduction, and survival.

Lahontan cutthroat trout (LCT) have an optimal growth and reproduction range between 13-15 degrees Celsius (Bear et al. 2007). LCT are known to show signs of acute stress at temperatures greater than 22 degrees Celsius. Therefore streams with maximum temperatures less than 22 degrees Celsius are considered resilient.

In terms of further future development, data for maximum summer temperature is only available for three streams in the Tahoe West project area. There is an opportunity to install more long term monitors in streams along the west shore with additional funding. We need to collect data on maximum daily temperature in all of the streams to develop a better picture of resilience.

10. Stream Channel Stability

The IADT recognizes the importance of stream channel (i.e. bed and bank) stability in resilient landscapes. However, channel stability is such a dynamic and variable indicator of ecosystem health, and at the landscape scale of the LRA for the LTW project, the IADT felt that the roads and trails linked to water channels, floodplain connectivity, and water quality indicators provide sufficient information related to channel stability without requiring extensive field reconnaissance or interpretation of existing data. Stream channel stability may be evaluated in future version of the LRA.

After conversations with stream and watershed specialists at the California State Parks and California Tahoe Conservancy regarding channel stability at the landscape scale, they agreed that although there are many available sources of channel stability information for west shore streams, determining an acceptable range of resilient conditions for a stream channel stability indicator is very challenging and not as meaningful at this large scale. Stream channel stability is impaired in many locations in the LTW project area, and stream restoration of these impaired reaches is important to consider during development of implementation strategies.

As the planning process moves closer to implementation, channel stability will be more specifically addressed to not only identify restoration opportunities, but also to determine where mitigation measures are necessary to protect vulnerable channel reaches during implementation of forest health treatments. There are several sources of channel stability information available for streams along Lake Tahoe's west shore, including the Lake Tahoe Basin Framework Implementation Study: Sediment

Loadings and Channel Erosion, the Ward Creek Ecosystem Assessment Report, and the Blackwood Creek Watershed Assessment.

11. Terrestrial Wildlife Forest Connectivity

The IADT plans to develop a quantitative, spatially explicit indicator for terrestrial wildlife habitat connectivity resiliency that will be in future version of the LRA. Complete development of this indicator was not possible during Phase 1 because of the availability of science team partners and the complexity of habitat data constraints.

The indicator will demonstrate the functional connectedness of older, late seral forests in the Lake Tahoe West landscape for the American marten. This habitat type was selected because older, more complex upland forests are limited on the west shore landscape, are a valued part of the landscape on the west shore, and support species that travel far distances and are sensitive to fragmentation. This forest type is also sensitive to disturbances such as climate change, drought, and fire. Marten is considered a strong indicator for habitat connectivity because this species prefers late seral habitat with complex forest structure, the species is also very sensitive to habitat fragmentation, has specific requirements for reproductive habitat, and travels on the ground as opposed to flying through the canopy. Importantly, the west shore is the principal landscape connecting marten north and south of the Lake Tahoe Basin. Keith Slauson with the Pacific Southwest Research Station of the Forest Service, and a member of the LTW science team, has developed a functional demographic model of marten habitat connectivity based on the characteristics of female reproductive home ranges in the Lake Tahoe Basin. He also has data to develop a model of genetic connectivity of martens. The marten data to be used in these models will be adapted for the Lake Tahoe West analysis area.

As part of this connectivity approach, Keith will also evaluate connectivity of habitat for California spotted owl and northern goshawk although these species do not have as extensive a data library as the marten does.

We prefer a functional connectivity approach, as opposed to structural, because unlike structural connectivity metrics, functional models take into account the structure of the habitat on the landscape as well as the behavior of the organism of interest that would move through the landscape. Essentially, habitat patches are “weighted” based on how easy or difficult it may be for the organism to use this habitat for various life history needs.

12. Riparian Connectivity: Stream Complexity

Stream complexity is a measure of stream habitat quality and aquatic connectivity. This indicator would be made up of several components, including amount of large woody debris, pool: riffle ratio, substrate, and riparian vegetation/shading. Streams with more complexity are more resilient to drought and climate change because they contain more microclimates which act as climate refugia for a variety of aquatic organisms.

Data on large woody debris, pool: riffle ratio, substrate, and riparian vegetation/shading are only available for three streams in the Tahoe West project area.

In terms of further future development, more extensive data collection is needed to evaluate these components for all of the remaining streams in the LTW project area in order to have a more complete picture of resilience. In addition, these components should be combined into a stream complexity index which might also include measures of bank stability and stream temperature.

Additional Indicators Considered but Unable to Develop at this Time

#	Name and Topic Addressed	Data Source	Why Removed
1	**Difference from Historic Land Surface Temperature**	ClimateEngine - LandSAT	Climatic Water Deficit (CWD) will perform better to predict mortality, but LST is an easier dataset to access.
2	**% bare ground (including roads) + slope** (or Annual runoff??): Soil erosion and delivery potential -> reduced resilience.	DEM, unknown % base ground (potentially veg type barren combined with NAIP) + roads - determine what Annual runoff in EcObject is - might be answer! (EcObject for % bare ground investigate succession and minimum mean height)	Replaced with water quality indicator.
3	**Retention of cool late season surface water** (more late season water more resilient for aquatic species)	Unknown	Future stream temperature monitoring conducted by the FS data can feed into assessment for this, but at this time no data available.
4	**Non-conifer cover surrounding water features** (assume shrubs resprout after fire more resilient water quality and aquatic habitats post fire (and pre fire). Provide shade in drought/cc conditions)	EcObject - SHUB_CFA (shrub cover) + HERB_CFA (herbaceous cover) + HDW_CFA (hardwood cover) in a defined buffer	Leave out unless do not have any other aquatic indicators because site might actually be more resilient after a disturbance – need species specific information to evaluate.
5	**Annual runoff** (Amount of water that exceeds total soil storage + rejected recharge) trying to determine a good metric for flood, this has potential but would want to discuss with soil person	EcObject	Evaluated other metrics
6	**Channel sinuosity** - possibly defined by slope, or only analyzed in meadows? water temperature would be linked to resilience of aquatic habitat for native species, versus opportunity for invasion from warm water invasive species	Unknown	Too challenging to get data

#	Name and Topic Addressed	Data Source	Why Removed
7	**Normalized differential vegetation index late season (NDVI)** - greenness (specific to meadows; for initial assessment could identify change points and/or evaluate variability in NDVI assuming meadow dominated by meadow vegetation would have less variability compared to meadow with conifers)	ClimateEngine - LandSat	There is currently a tool being developed to evaluate meadow restoration and work is being done to evaluate how to utilize the tool for changes in climate. Once the tool is developed this would be a good metric to revisit.
8	**Known invasive species** (there would be reduced resilience to invasive species where they are already existing)	agency data of where known invasive species are	Replaced with desire for composite indicator on % bare soil and also access-specific indicator: feet of trails and roads, number of access points (access between meadows/lakes), addresses chytrid (access between meadows/lakes).
9	**Chytrid fungus,** as indicator of climate change (temperature) and invasives	unknown	Data is sparse
10	**Air quality: number of popular complaints**		This is a “first generation” indicator designed to track ongoing public concern with smoke impacts. We realize that quantification of complaints is currently subjective and the process of tracking public views of smoke impacts from management actions will need improvement in future years. This indicator will not be included in our landscape resilience assessment at this time.
11	**Range of veg change (treatments)** -	based on Edart	Still under development - doesn't pick up understory/low impact treatments, but good for showing mortality, large fires, large treatments

#	Name and Topic Addressed	Data Source	Why Removed
12	**Magnitude of change** -- Direct measure of how resilient the landscape is to tree mortality (i.e., insects & disease as a disturbance), it can be an indicator of where to focus efforts	For initial assessment EcObject change value (Veg change post LiDAR aquisition OR Map Update Cause) which is based on EDART (make sure to identify change from treatments versus mortality)	EDART (while this dataset is not publicly available currently, it should be soon and it is an excellent dataset for evaluating mortality on the landscape)
13	**Scenic stability**		

Appendix E – Next Steps, Future Updates to Existing Indicators

Contents

Individual Indicators

This describes those indicators (individual and composite) for which the Lake Tahoe West (LTW) Interagency Design Team (IADT) has identified future development steps for indicators that have been assigned a resilience value. Not all indicators have future steps identified and so those are not listed in this appendix. As the LRA is refined in future versions, and the Landscape Restoration Strategy (LRS) moves forward, this appendix too will be refined and updated.

Fire Risk Index

In terms of future development, the Modified Fire Risk Index combines data from a multi-state regional effort with forest structure information gathered through LiDAR. Additional clarity in assessing resilience would be provided through better representation of understory vegetation structure and composition, which drives surface fire behavior and ultimately determines a wildfires capability to transition into tree canopies. Efforts are underway using Terrestrial Laser Scanning to better be able to assess available fuel, which will provide more reliable fire behavior calculations.

The Modified Fire Risk Index primarily indicates fire threat and effects in terms of direct flame impingement. It therefore underestimates potential effects to Public Health and Safety caused by ember and smoke production. Data is currently being collected to capture building characteristics and defensible space compliance throughout the Lake Tahoe Basin, and complete coverage is expected within several years.

Better predictions of fire behavior along with a better understanding of which developed areas more or less vulnerable are based upon the level of community preparedness will allow for the development of a replacement for the Modified Fire Risk Index. The replacement data set would be more sensitive to land management and community actions such as fuel reduction treatments and the creation of defensible space, and could be more easily updated to monitor effectiveness and manage adaptively.

Trees Per Acre

Additional data that would be valuable to further develop this indicator would include:

- TPA by species composition;
- Reference data for trees per acre by seral stage;
- TPA for aspen, rather than SDI;
- Reference data for TPA specific to small trees and improved methodology for capturing small trees in TPA data;
- Additional references to improve desired TPA for subalpine;
- Additional references to provide desired conditions for riparian;
- We need a shrub metric, however there is not currently one available. Shrubs are important since a low density forest would not be resilient to fire and drought if it had 100% shrub cover (see shrub metric that is not available).

Meadow Refugia and Connectivity

Additional data that would be valuable to further develop this indicator would include: updated analysis, new climate models and utilization of NDVI or NDWI once tools are developed.

Roads and Trails Linked to Water Channels

This indicator can be improved upon during the science modeling in Phase 2 to allow for consideration of other appropriate BMPs. Better data on culverts (e.g., functioning, undersized) and other existing rock armoring/BMPs needs to be collected, but likely will not be available in Phase 2. Data collection and monitoring will be important elements for project planning in Phases 3, 4 and 5.

Aquatic Organism Passage

In terms of future development, it would be valuable to examine natural barriers in addition to man-made barriers. Also, it would be valuable to look at this indicator in conjunction with native fish diversity, stream temperature, and macroinvertebrate data maintained by TRPA (Muskopf pers. comm. Sept. 13, 2017). The USFS aquatic biologist, Sarah Muskopf, warns not to look at this metric by itself because Highway 89 is a major barrier to nearly all creeks, even those like General Creek that is considered relatively good habitat for native fish.

Floodplain Condition

This indicator could be improved by including other metrics of floodplain condition. These could include a direct measure of channel entrenchment, which would tell you about the ability of water to reach and stay on the floodplain. While this is usually collected through field observations, there may be new LiDAR based technology that could provide this information. Metrics related to the species composition and quality of vegetation within floodplains and stream environment zones (SEZs) could include conifer versus riparian species (possibly from remote sensing) or NDVI (normalized difference vegetation index) which addresses vegetation greenness and therefore is used to measure vigor in the late summer.

Bark Beetle Predator

This analysis will need to be updated with the new LiDAR flight to reflect changes in forest structure, and how those changes influence estimates of occupancy for these bird species. We will also need to work with scientists to define a minimum patch size that would be suitable to support bird territories.

Native Fish Diversity

Moving forward, for future development, we should also note if the stream dries up seasonally, rank each watershed by size, and determine how far up the stream native species can be found.

For further development (Phase 2), we should take into account the abundance of the fish that have been found for a measure of diversity that takes into account evenness. For example, McKinney has more native than non-native species but the non-native species outnumber the native species by 3,462 individuals. So in essence, we know the stream can hold a relatively large amount of fish, and can support a diversity of native species, but it is heavily populated by nonnative individuals. Sarah states that a single-species stream or only non-native species stream is considered not resilient (Muskopf, pers. comm. Sept. 13, 2017).

Seral Stage

Additional data that would be valuable to further develop this indicator would include:

- Development of stand scale desired conditions;
- Additional references to provide desired conditions for riparian;
- Additional references to provide desired conditions for Aspen;
- Additional references to provide desired conditions for subalpine.

Vertical Heterogeneity

Additional data that would be valuable to further develop this indicator would include:

- Development of stand scale desired conditions;
- Incorporate additional references that are relevant to vertical heterogeneity to expand range of desired conditions.

Horizontal Heterogeneity

Additional data that would be valuable to further develop this indicator would include:

- Development of stand scale desired conditions;
- Incorporate additional references that are relevant to horizontal heterogeneity to expand range of desired conditions.

Vegetation Type

Additional data that would be valuable to further develop this indicator would include:

- Development of stand scale desired conditions;
- Incorporation of future climate is important. Climatic water deficit could be used in combination with restoration plans to identify where a vegetation type more resilient under hotter conditions may succeed. For example an area may be more suitable to be managed as a mixed conifer hardwood compared to a moist mixed conifer.

Composite Indicators

There is interest among the IADT and Science Stakeholder Committee (SSC) to evaluate additional composite indicators that are relevant to specific elements (e.g., species-specific habitat) that are sensitive to disturbances on the landscape from multiple indicators that don't happen to be already neatly packaged in one of the composites we have already developed. For example, there is interest in developing a California spotted owl and northern goshawk Protected Activity Center (PAC) composite indicator. To develop this type of theme-based composite, the IADT with input from the SSC, would select those indicators that contain information relative to PAC habitat resilience and combine those into one individual composite for PAC resilience.