The Sierra Nevada Adaptive Management Experiment (AMEX) is a large-scale, replicated experiment utilizing progressive, scientifically-supported silvicultural treatments to increase resilience, resistance, and adaptation capacity of California’s Sierra Nevada mixed conifer forests. The experiment is designed to generate and track long-term changes in forest composition, structure, and function under ongoing and future climate change, and treatments represent a basic suite of plausible approaches that managers may feasibly take to address ongoing and novel stresses to forest ecosystems.

This project is a collaborative effort amongst foresters and ecologists in academia and state and federal land management agencies, with fully-replicated treatments installed on state (LaTour and Mountain Home Demonstration State Forests) and private (UC Berkeley’s Grouse Ridge Forest) forests paired with companion sites on federal land (Stanislaus-Tuolumne and Eshom Forests).
Over four degrees latitude from the northern to southern Sierra Nevada (Shasta to Tulare counties), this long-term, multi-decade study will compare treatments representing fundamentally different climate change impact scenarios and a suite of potential approaches forest managers may take to mitigate impacts on the ecological, economic, and social services provided by forest ecosystems.

Ongoing and predicted impacts to forests include regeneration failures, shifts in species' ranges, drought mortality, and increasing severity of disturbances, such as bark beetle outbreaks and/or fire. These changes are creating uncertainty in how forests will function in the future and concerns around sustaining ecosystem goods and services. This cooperative, interagency plan will utilize a diverse range of silvicultural tools to reduce carbon loss and to return drought- and beetle-impacted Sierra forests from carbon sources to carbon sinks.

The foresters leading this project are dedicated to maintaining experimental sites to facilitate continued carbon sequestration and other ecosystem services while also tracking effectiveness of these varying intensity treatments.

**RESILIENCE**

**Resilience treatments** closely mimic forest structure under historic fire conditions of the Sierra Nevada and are designed to prepare the forest for disturbance by creating stand conditions that will facilitate recovery of pre-disturbance forest conditions. These treatments mitigate climate change effects and reduce the likelihood of requiring assisted recovering following disturbance or catastrophic climate impact through retention of diverse species and structures. Resilience treatments are comparable to conventional density management in the Sierra Nevada and will create a patchy matrix with high structural heterogeneity and species diversity while retaining locally rare species (e.g. giant sequoia at southern properties).

**RESISTANCE**

**Resistance treatments** are aimed at reducing fuel loading and will prepare the forest to resist a disturbance by creating stand structure that is open, park-like, and forces fire to stay on the ground. While some change following a future disturbance may occur, it is assumed that change will be small enough in these treated stands so that the fundamental structure and composition needed to sustainably resist future disturbances remain intact. These treatments favor large trees that can rapidly respond to release and increase in average diameter. Treatments further change stand structure by removing ladder fuels and increasing spacing among trees. Opening of the understory will allow for utilization of these materials while also supporting the establishment of new cohorts of species at varying intervals. Resistance treatments lead to low stocking with retention focused on large, healthy trees across a diversity of species. Foresters will retain the largest trees of diverse species, using high leaf area, as opposed to stem form, as a deciding factor in marking (i.e. high leaf area = assumed more resistant to stress).
Transition treatments will work to actively help the forest adapt to changing climate, representing the scenario where resistance and resilience treatments are not effective and the forest cannot recover without intervention. Treatments mimic a disturbance that fundamentally changes the composition and structure of the forest. In this treatment, foresters will use group selection to favor large, live trees but also create large gaps for reforestation. Canopy gaps will cover 10% of transition treatment area, with gaps ranging from 0.25ac to 1ac openings. A provenance test of seed sources will be used to reforest the properties, which will require annual visits to track success and maintain treatments. Foresters and property managers are recommitted to protecting seedlings and treating as needed. A diversity of species and seed sources (provenances) will be selected for reforestation, which will include both local populations and those predicted to be better adapted to current and future climate conditions. Available seed by species and population for each seed zone have already been identified in collaboration with the Cal Fire State Seed Bank at the L.A. Moran Reforestation Center. Transition treatments will create a low stocking matrix with large canopy openings to facilitate planting trials of seed from different provenances and species that are predicted to be better adapted to future climate conditions. These seedlings are the future forest and will need to endure ongoing changes in climate while growing into the canopy.

Control treatments will maintain untreated areas so that the relative effects of treatments can be assessed. Importantly, controls also represent the plausible alternative that a hands-off approach may in some cases be appropriate given certain climate scenarios. While the context of this study primarily assumes that pro-active management will likely be necessary to sustain forest values into the future, it is also critical to actively test a broad set of approaches— including a hands-off approach.
PROJECT OVERVIEW

As the climate changes, forests are experiencing increasing frequency and severity of disturbances and mismatches between available habitat and climatic conditions (Turner 2010). Ongoing and predicted impacts to forests include regeneration failures, shifts in species' ranges, drought mortality, and increasing severe disturbances (e.g., bark beetle outbreaks and/or fire). These changes are creating uncertainty in how ecosystem dynamics will function in the future as concerns around sustaining ecosystem goods and services (Seidl & Lexer 2013). Inhibition of conifer regeneration, for example, can lead to ecosystem conversions and/or long-term changes in stand dynamics, and this concern is magnified in already warm, dry, lower montane systems.

The fact that future conditions will be different from those of the past and the present forces us to step back and rethink the way we manage forests (Peet 2007). The objective of management needs to be in maintaining desired forest characteristics, such as goods and ecological services, when faced with drought, insects, fire, and warming. Foresters can tackle this challenge head on by building resilience and resistance into the landscape (DeRose & Lon while also planting species better adapted for future (rather than current) conditions (Aitken & Bemmels 2016).

This Sierra Nevada-wide project will utilize progressive, scientifically-supported silvicultural treatments to increase resilience, resistance, and adapt capacity of Sierra Nevada mixed conifer forests. This work builds on the foundation for management and experimentation laid out by the National Adaptive Silviculture for Climate Change network (Nagel et al. 2017). As the climate changes, foresters will need to be proactive to reduce the risk of these mass (C) sinks becoming C sources and to mitigate predicted impacts to forests, including regeneration failures, drought mortality, and catastrophic wildfire. Foresters leading this collaborative project will tackle this challenge by building resilience and resistance into the landscape while reforesting with species adapted for future climate conditions to ensure ongoing C sequestration across the landscape.

TREATMENT DESIGN & LINK TO ADAPTIVE CAPACITY

In Sierra Nevada Adaptive Management Experiment, state and private foresters will implement these concepts on the ground through resilience, resiliency, transition methods of management. These treatments are designed to generate and track long-term changes in forest composition, structure, and function under current and future climate changes. Foresters are dedicated to maintaining these as permanent treatments to facilitate continued C sequestration other ecosystem services while also tracking effectiveness of these varying intensity treatments. Treatments are meant to represent a basic suite of approaches that managers may feasibly take to address ongoing and novel stresses in forests related to climatic change. Following this design, four treatments will be installed and replicated at the stand level (4 treatments x 3 replicates x 20 acres per replicate = 240 acres); in some areas, treatments will be do allow for a fire or fire surrogate operation to one full replicated set (4 treatments x 3 replicates x 20 acres per replicate x 2 fire or fire surrogate treatment areas).

Resilience treatments closely mimic forest structure under historic fire conditions and are designed to prepare the forest for disturbance by creating conditions that will facilitate recovery of pre-disturbance composition and structure. These treatments mitigate climate change effects and reduce the need of requiring assisted recovering following disturbance or catastrophic climate impact through retention of diverse species and structures. Resilience treatments are comparable to conventional density management in the Sierra Nevada and will create a patchy matrix with high structural heterogeneity and species diversity while retaining locally rare species (e.g., giant sequoia at southern properties).
Resistance treatments are aimed at reducing fuel loading and will prepare the forest to resist a disturbance by creating stand structure that is open, and forces fire to stay on the ground. These treatments favor large trees that can rapidly respond to release and increase in average diameter. Treatments change stand structure by removing ladder fuels and increasing spacing among trees. Foresters will retain the largest trees of diverse species, using high area, as opposed to stem form, as a deciding factor in marking (i.e. high leaf area = assumed more resistant to stress).

Transition treatments will work to actively help the forest adapt to changing climate, representing the scenario where resistance and resilience treatments are not effective and the forest cannot recover without intervention. Treatments mimic a disturbance that fundamentally changes the composition and structure of the forest. In this treatment, foresters will use group selection to favor large, live trees but also create large gaps for reforestation. Canopy gaps will create transition treatment area, with gaps ranging from 0.25 ac to 1 ac openings. Transition treatments will create a low stocking matrix with large canopy openings to facilitate common garden trials. A diversity of species and seed sources (provenances) will be selected for reforestation, which will include both local and those predicted to be better adapted to current and future climate conditions. These seedlings are the future forest and will need to endure ongoing climate while growing into the canopy.

Controls will maintain untreated areas so that the relative effects of treatments can be assessed. Importantly, controls also represent the plausible alternative to a hands-off approach that may in some cases be appropriate given certain climate scenarios. While the context of this study primarily assumes that management will likely be necessary to sustain forest values into the future, it is also critical to actively test a broad set of approaches, including a hands-off approach.

Flexibility in Treatments: Resilience and resistance treatments use historic natural conditions and treatments as guideposts, acknowledging that coniferous forest structure may depart from these conditions with climate change, as seen with extreme drought mortality in Sierra Nevada. Our targets are in maintaining forest ecosystem function, forests as forests, and the desired services provided by these ecosystems.

LITERATURE CITED

BENEFITS

Project activities will support a suite of ecosystem services across the western Sierra Nevada by creating structural heterogeneity and plant communities at the stand, landscape, and regional scales. Structural heterogeneity facilitates wildlife movement via patch diversity and intact corridors while supporting more species under both current and future conditions. Transition treatments are aimed at insuring continued forest cover under future conditions, maintaining sequestration over a 100 year rotation while also providing for continued forest cover for wildlife. The planting of provenances better adapted to future conditions will make these forests more resilient to climate change in the long-term, allowing for perpetuation of ecosystem services. Fuels reduction across core properties will have a wide-reaching impact on watersheds and downstream users by reducing sedimentation, maintaining water quality, providing a continued source of upland water for downstream users. Biomass removed via harvest will be stored long-term in wood products product mills (e.g. Sierra Forest Products in the southern Sierra Nevada).

All actions will lead to immediate short-term C sequestration through release of large-diameter trees and long-term C storage through reforestation. Regular maintenance of proposed conditions. Foresters are managing state and private working forests and committed to perpetuating the structural of the project.

FURTHER READING