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Mature and Old-Growth Forests: Analysis of Threats on Lands Managed by the Forest Service and Bureau of Land Management

in Fulfillment of Section 2(c) of Executive Order No. 14072

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Executive Summary

This report was prepared in response to Executive Order (E.O.) 14072, which instructed the U.S. Department of Agriculture (USDA), Forest Service and U.S. Department of the Interior, Bureau of Land Management (BLM) to analyze threats to mature and old-growth forests on lands managed by these agencies and implement a series of actions intended to foster resilience in the Nation's forests.

This is the second report regarding mature and old-growth forests prepared in response to E.O. 14072. The first report, "Mature and Old-Growth Forests: Definition, Identification, and Initial Inventory on Lands Managed by the Forest Service and Bureau of Land Management" was completed in April 2023 (revised April 2024). This report details the initial analysis of threats to the mature and old-growth forests inventoried in the first report.

The initial threat analysis found that mature and old-growth forests have high exposure to a variety of threats—climate and disturbance projections show this exposure will likely increase. Currently, wildfire, exacerbated by climate change and fire exclusion, is the leading threat to mature and old-growth forests, followed by insects and disease in the West, while more varied disturbances threaten older forests in Alaska and in eastern regions. The analysis also found that two-thirds of mature forests and just over half of old-growth forests are vulnerable to these threats. Tree cutting (any removal of trees) is currently a relatively minor threat despite having been a major disturbance historically, as from 1950 to 1990 these practices were the primary reason for loss of old-growth forests.

Since 2000:

- Wildfires were associated with a net decrease of 2.6 million acres of mature forest, and 700,000 acres of old-growth forest.
- Insects and disease corresponded with a net decline of 1.9 million acres of mature forest and 182,000 acres of old-growth forest.
- Tree cutting that resulted in 24 percent-or-more basal area loss by the Forest Service and BLM was associated with a net decrease of 214,000 acres of mature forest and 9,000 acres of old-growth forest.
- Where no severe forest disturbances have occurred, mature forests had a net increase of 2.21 million acres and old-growth forests by 1.20 million acres.
- Combined, there has been a 2.51-million-acre net decline of mature forests, with about a tenth of this becoming old growth (a 0.28 million acre net increase in old growth).

Projections over the next 50 years show growth of young and mature forests may result in an increase of older forests, despite increased disturbances. However, gains lessen with each passing decade and the expanding wildland-urban interface complicates mitigation of threats. Projections of increasing mature and old-growth forests are tempered by the reality that American forests are entering uncharted territory with climate change. Climate change has already increased threat levels and is altering where, and what types of, mature and older forest can persist.

This introductory threat analysis should be considered a first step towards understanding the myriad interacting biophysical and social factors that threaten the persistence of older forests on public lands across the Nation. This initial threat analysis, and future monitoring of the status, trends, and disturbances of these forests will inform understanding both causality for observed patterns and associated climate-informed adaptive management options. Most importantly, the likely environment of the future, not that of the past, should guide mature and old-growth forest policy and management considerations. As our understanding of the implications of climate change evolves, so will understanding the places and methods to best steward and conserve our Nation's older forests.

Old-growth stand on Bitterroot National Forest, Montana. USDA Forest Service photo by Shelagh Fox.

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Introduction

E.O. 14072 (also known as "Strengthening the Nation's Forests, Communities, and Local Economies") instructed the Department of the Interior, Bureau of Land Management (BLM) and U.S. Department of Agriculture (USDA), Forest Service to implement a set of actions focused on the health of the Nation's forests. Section 2(c).ii specifically directed the agencies to analyze the threats to mature and old-growth forests on associated Federal lands, including from wildfires and climate change. To fulfill this direction, the agencies created this report.

The analysis in this document is based on the initial inventory and definitions of mature and old-growth forests described in the report, Mature and Old-Growth Forests: Definition, Identification, and Initial Inventory on Lands Managed by the Forest Service and Bureau of Land Management in Fulfillment of Section 2(b) of Executive Order No. 14072 (USDA and USDI 2023—hereafter, referred to as the mature and old-growth forest inventory report; Pelz et al. 2023, Woodall et al. 2023, Gray et al. 2023). The mature and old-growth forest inventory report was also a fulfillment of Section 2(b) of E.O. 14072, which was released to the public on April 20, 2023.

Interest in the Nation's mature and old-growth forests, specifically what remains on federally managed lands, has been increasing since the 1980s (USDA Forest Service 1989). A series of recent governmental actions highlight the increased national interest (appendix 1).

For this analysis, threats are defined as disturbances or stressors, either current or projected, that can contribute to the enduring loss or degradation of the characteristic conditions, functions, or values of existing mature and old-growth forests. Threats identified in the Executive order include wildfire, climate change, insect outbreaks, disease, and decades of fire exclusion. However, recognizing the vast geographic diversity in mature and old-growth forests as well as disturbances, social, cultural, and economic conditions across the Nation, each Forest Service region was asked to review and expand upon (if necessary) the list from the Executive order. The result added invasive species, impacts from large mammal foraging, ungulate browsing, human activities, and management approaches and challenges (including those derived from policy and social restrictions on management). Multiple forms of engagement with Tribal leaders, stakeholders, the public, and Forest Service and BLM staff yielded additional inputs, such as: threats from timber harvest and vegetation management, natural disturbances, and human activities (such as road construction, expansion of the wildland-urban interface, and activities on State and private lands adjacent to Forest Service and BLM forestlands [see appendix 2]). Given time and data constraints, this report analyzed the following potential threats to lands managed by the Forest Service and BLM:

- Fire
- Fire exclusion
- Insects and disease
- Extreme weather events
- Climate change
- Tree cutting
- Roads

In this report, the characterization of threat considers two criteria:

1. The direct effects that result in losses of mature or old-growth forest based on the definitions from the mature and old-growth forest inventory report (USDA and USDI 2023), including outcomes that could result in future or enduring loss, such as from climate change.
2. Context-based consideration for whether effects result in adverse outcomes for ecological, social, cultural, and economic values.

American society's values for, benefits from, and manners of interaction with mature and old-growth forests could be associated with individual forest components, such as individual trees, or those broadly spread across a region. They might be associated with a specific forest type and are generally uniformly distributed across a forest. Consideration of socio-cultural valuation associated with forest ecosystems has become increasingly significant in Western scientific literature (Velasco-Muñoz et al. 2022). This includes scientific literature highlighting values associated particularly with old growth and arguing to ensure its future existence. These changes are commonly linked to a record of focus on timber (Moyer et al. 2008) as well as changes in forest values, especially after the second half of the 20th century (Bengston 2020). Of note, literature highlighting values associated particularly with old growth has become more distinct as well as arguments to ensure its future presence. For example, “Large old trees are an important part of our combined cultural heritage, providing people with aesthetic, symbolic, religious, and historical cues. Bringing their numerous environmental, oceanic, ecological, therapeutic, and socio-cultural benefits to the fore, and learning to appreciate old trees in a holistic manner could contribute to halting the worldwide decline of old-growth forests” (Gilhen-Baker et al. 2022).

Forest managers and policy makers must carefully consider and balance multiple forest values that are commonly marked by contradiction and uncertainty (Anderson et al. 2018). The spectrum of values has been both revealed through—and amplified by—the increase in public input. Particularly with the institution of the National Environmental Policy Act (1970), public interest and participation in the planning process has dramatically increased, including in forest management (such as Paletto et al. 2013). An additional factor is the recent, greater inclusion and participation of historically marginalized and underserved communities when it comes to understanding forest values (Charnley et al. 2008).

Methods

Qualitative and quantitative analytical methods were used to analyze the potential threats to mature and old-growth forests. The intent was to integrate the biophysical, socioeconomic, and cultural evaluations. Much of this analysis used the Forest Inventory and Analysis (FIA) spatially balanced network of field plots across the United States; FIA formed the foundation for the mature and old-growth forest inventory report. Because FIA plots are monumented and remeasured on a 5 to 10-year cycle, depending on location, and are located within lands managed by the Forest Service and BLM, they provide an unbiased assessment of current forest condition and trends over time. Condition-based evaluations, remeasured FIA plot analyses, projections of the FIA inventory into the future, as well as spatial analyses to examine recent historical, current, and future conditions and exposures to potential threats were used in this analysis. These methods complemented each other, providing a rich understanding of past and future threats to the Nation's mature and old-growth forests. Each approach is briefly described in the following sections.

The analyses in this report encompass land managed by the Forest Service and BLM. In many places of this report, the data is summarized by Forest Service region, but include data for both the Forest Service and BLM. This was mutually agreed upon by both agencies.

Condition-Based Evaluations

We examined the relationship between forest disturbances and threats through a qualitative condition-based evaluation—an examination of the influence of initial forest conditions on the outcome (positive, neutral, adverse) of a disturbance (such as fire or forest insects). This analysis combined principles and observations from disturbance ecology with adverse outcome criteria adapted from Environmental Protection Agency (EPA) evaluations and the definition of adverse outcome used in environmental threat analyses (Brown et al. 2017).

Whether or not disturbances constitute threats to mature and old-growth forests depend on their severity and duration (first box—Driver/Stressor), the local

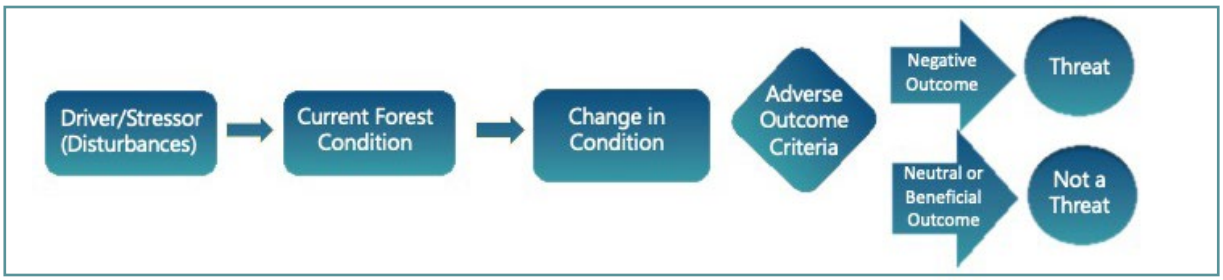


Figure 1.—Illustration of the framework adapted from EPA (Brown et al. 2017) and employed to identify when a disturbance such as fire—a driver or stressor—results in a threat versus an outcome that is neutral or beneficial. This framework is particularly applied in the qualitative, condition-based evaluation reviewed for each potential threat in the results.

ecological, social, economic, and cultural conditions under which the disturbance occurs (second box—Current Forest Condition), and the nature of change resulting from the disturbance (remainder of figure 1). Applying adverse outcome criteria that reflect the ecological, social, economic, and cultural values of mature and old-growth forests helps to determine if a change in condition is considered a negative outcome (top arrow of figure 1) or a neutral or beneficial outcome (bottom arrow of figure 1). Disturbances that result in a decline in the abundance of desirable mature and old-growth forest, or an enduring loss of mature and old-growth conditions, functions, or values were considered as having negative outcomes, and thus identified as *threats*. Disturbances that resulted in neutral or beneficial outcomes, such as no change in abundance or an increase in the extent of mature and old-growth forest, were not considered threats (see following example).

The example (box 1) illustrates that we recognize an ecological adverse outcome when the change in condition following a disturbance results in the forest no longer being classified as mature or old growth. When the condition of mature or old-growth longleaf pine forest includes dense trees with ladder fuels, a crown fire capable of removing the large trees would be likely and the forest would be transformed to an earlier developmental stage. Because of the forest condition, fire resulted in the adverse outcome of losing the largest and oldest trees. The fire, in an uncharacteristically dense stand, was a clear threat to the mature or old-growth forest component. The condition-based analysis also considers outcomes evaluating social, cultural, and economic values. Assessing threats, particularly through a social, cultural, and economic lens begs the question, "of what, to what, and to whom?" Ecological disturbances may change a range of forest conditions but may not alter their value to humans. This report explores a small subset of social, cultural, and economic values to ground the ecological outcomes in the human environment in which they occur, as the next example shows (box 2).

Fire is a very common disturbance affecting many types of forests. However, fire is not always a threat. Frequent, low-intensity surface fires (driver) may burn through many hundreds of acres of mature or old-growth longleaf pine forest without removing the mature or old-growth forest component. The forest condition is such that the fire remains a surface fire based on the absence of dense trees or other fuels that would change the fire to a widespread crown fire (stressor). Alternatively, if the condition of a mature or old-growth longleaf pine forest includes dense trees with ladder fuels, a crown fire capable of removing large swaths of large trees—an adverse outcome—would be likely, and the forest would be transformed to an earlier developmental stage. Because of the forest condition, which in this second case was uncharacteristically dense, the fire was a clear threat to the mature or old-growth forest component.

Box 1.—Example of how forest conditions influence a disturbance as a threat.

Many mature and old-growth forests support unique medicinal plants and other features that are a source of important cultural values. For example, some Tribes and Alaska Native populations use exceptionally large trees to build canoes, housing, and other structures. Very large birch, large yellow cedar, and other large trees are harvested and play a critical role in the cultural life of peoples that live near mature and old-growth forests. A disturbance may kill the species of tree used for the cultural resource, such as yellow cedar, without killing other species of trees. Consequently, a disturbance may result in a cultural adverse outcome (such as death of most large yellow cedar) in a stand that remains classified as old growth based on remaining forest structural components for that old-growth forest type.

Box 2.—Example of a disturbance resulting in an adverse outcome for social and cultural values.

Ecological and social factors interact in complex ways, which can influence whether the outcome of a disturbance results in a threat and what form it takes. The Executive order clearly framed the importance of mature and old-growth forests to social, cultural, and economic values. Forests, and the physical changes they undergo, are better understood when viewed in the context of the relationships that humans have with them. This enables a richer discussion on what the physical changes mean to wide ranging groups of people and interests. For this analysis, the Forest Service and BLM explicitly integrated social, cultural, and economic lenses with ecological lenses when evaluating threats. This helped inform how the ecological, social, cultural, and economic outcomes from a disturbance (whether a threat or not) differ. Outcomes from disturbances are generally threats to the ecological structure of mature and old-growth forests if they change a stand's classification to an earlier stage of development. Threats could be defined differently. For this national evaluation we defined threats to ecological conditions as a change in developmental stage. Determining whether disturbances lead to other negative ecological, social, cultural, and economic outcomes requires local context.

Forest characteristics as well as the local social, economic, and cultural environment—identified as critical in these analyses in determining whether a disturbance results in a threat—are often fine-grained and beyond the resolution of a national evaluation. As a result, this report generally does not attempt to identify specific values threatened by specific stressors in specific locations. Rather it identifies patterns that illustrate potential threats at broader scales that can ultimately be analyzed more effectively at local scales. This qualitative, condition-based evaluation provides the knowledge to place potential threats in context for informed, future local evaluation.

Worksheets (see methods in appendix 3) were completed by several resource specialists (for example, social scientists,

ecologists, and silviculturists) in each Forest Service region to inform the condition-based evaluation. The goal of the worksheets was to systematically examine the forest conditions that determine whether various disturbances result in an adverse outcome—and thus constitute a threat—or produce a neutral or beneficial outcome. These expert elicitations, a social science method by which experts in their fields make statements that can be trusted as information, brought local information to the analysis, and made it more context specific, adding to what exists in the published literature. This framework was used to examine disturbances such as fire or hurricanes in relation to different forest types and structural stages, providing critical context for how drivers and stressors affect diverse types of mature and old-growth forests in different regions.

Remeasured Forest Inventory and Analysis Plots

An analysis of FIA plot data was used to estimate the net change in mature and old-growth forest acreage. This analysis used FIA plots that were measured more than once between 2000 and 2020 (measurement year and remeasurement intervals vary by State; see appendix 4). In addition to site and detailed tree information, FIA field crews record disturbances that have occurred, to include: fire (both wildfire and prescribed fire activities), insect and disease, animal damage, weather damage, and geological disturbances. Disturbance is recorded when it is at least 1 acre in size, there is mortality and/or damage to 25 percent of all trees in a stand, or 50 percent of

Old-growth stand on Bitterroot National Forest, Montana. USDA Forest Service photo by Shelagh Fox.

an individual tree species is affected. If a disturbance affects land and/or vegetation, but not initially the growth and health of the trees, such as grazing and flooding, then it is recorded when at least 25 percent of the soil surface or understory vegetation has been affected. Cutting—the removal of trees due to a silvicultural treatment, including thinning of smaller diameter trees and/or harvesting of larger diameter trees with the intention to move the stand from its current condition towards a desired future condition—is recorded when the treatment is at least 1 acre in size. Cutting does not include sparse removals of firewood or Christmas trees (USDA Forest Service 2024). Disturbance and cutting are recorded on a plot if they occurred since the previous measurement. For this analysis, disturbance and cutting were grouped by disturbance type. A hierarchical grouping was applied; if either fire or cutting were identified, those stands were classified as "cut" or "fire" (a subset where both occurred were classified as "cut+fire"). If neither of those were present, but insect or disease damage was present, then "insect/disease" was classified. If none of the above were present, then "weather" disturbance was classified. This could include extreme drought mortality, wind damage, avalanches, floods, and landslides. More information on FIA disturbance codes is available from Burrill et al. (2023).

Disturbance severity was classified by the percentage of live tree basal area[1] change between the first and second measurements:

- Low basal area loss (**Low**): less than 25 percent basal area loss (including basal area gain)
- Moderate basal area loss (**Mod**): 25–60 percent basal area loss
- Moderately severe basal area loss (**ModSev**): 60–90 percent basal area loss
- Severe basal area loss (**Severe**): equal to or greater than 90 percent basal area loss

Mature and old-growth forest FIA plots were identified using definitions and criteria applied in the initial mature and old-growth forest inventory report (USDA and USDI 2023). Results are first presented in terms of mature and old-growth forest at the initial measurement (Woodall et al. 2023) that experienced disturbance during the remeasurement period. Because a disturbance can cause a forest to either gain or lose mature or old-growth status, or a forest may change status regardless of direct disturbance effects, the impacts associated with the occurrence of disturbance are expressed as the net change in status, regardless of the status at the first measurement. The magnitude of change is expressed in acres as well as the percent of forest area in mature or old-growth status at the initial measurement. The area estimates represent change over an average period of 9 years between plot measurements, with most initial measurements occurring in the 2000s (2000–2009) and remeasurements occurring in the 2010s (2010–2019) (appendix 4). Some results

1 Basal area is the cross-sectional area of the boles of a tree in a stand (for example, ft^2/ac), generally measured 4.5 feet above the surface of the ground.

are presented by forest type group (Perry et al. 2022), which is a classification based on the dominant species in a stand (Burrill et al. 2023, appendix D). Statistical significance of change is assessed using 95-percent confidence intervals of the sampling error estimated from standard FIA post-stratified estimation techniques (Bechtold and Patterson 2005).

Forest Inventory and Analysis Data Projected into the Future

An analysis of forest inventory projections was used to estimate net change in future mature and old-growth forest acreage under climate and socioeconomic scenarios. The Resources Planning Act (RPA) Assessment's Forest Dynamics Model (FDM) is a stochastic modeling system that projected observed (2000–2019) FIA plot-level variables in 2020 forward to the period 2030–2070 for the contiguous United States (Coulston et al. 2023). Projections were based on observed relationships between plot conditions in the observed FIA inventory and environmental and socioeconomic variables, including climate, timber prices, human population, and income based on location of the plot. Plot conditions are projected under future scenarios by a set of sub-models representing harvest choices, forest disturbance, growth, aging, regeneration, and forest type transitions over time (Coulston et al. 2023). We used results from the FDM to quantify the projected live volumes affected by harvest and wildfire in mature, old-growth, and nonmature as well as the projected areas of those forests over time. Relationships were modeled separately by RPA region and ownership to incorporate regional patterns.

- **Future wildfire sub-model**—This sub-model is based on past tree mortality resulting from fire recorded on FIA plots. Because of the limited ability of FIA field crews to detect low-severity fires, fires that did not lead to tree mortality are omitted. Thus, the projections represent annual volumes of tree mortality resulting from moderate and high-severity wildfires over time (Costanza et al. 2023). This sub-model links to other sub-models that modify forest fuel characteristics over time, including basal area, down woody material, stand age, tree species composition, and harvest probability over time in response to the scenarios described below.
- **Future harvest choice sub-model**—This sub-model is based on empirical relationships linked to prices and demand for wood nationally and globally. These relationships were modeled separately by RPA Assessment region and varied by land ownership and management practices. Historical price sensitivities of different forest ownership categories were accounted for.

We used future scenarios developed for the 2020 RPA Assessment to project the FIA inventory over the next 50 years. The four RPA Assessment scenarios incorporate future climate, population, and socioeconomic change by pairing two alternative atmospheric warming futures (Representative Concentration Pathways, or RCPs) with four alternative socioeconomic futures (Shared Socioeconomic Pathways, or SSPs) in the following combinations (see O'Dea et al. 2023 for more information on scenarios):

1. high warming and high growth (**HH**) – RCP8.5 and SSP5
2. high warming and moderate growth (**HM**) – RCP8.5 and SSP2
3. high warming and low growth (**HL**) – RCP8.5 and SSP3
4. lower warming and moderate growth (**LM**) – RCP4.5 and SSP1

Within each RPA scenario, projections were made using five different climate models (Global Circulation Models, or GCMs), selected to capture a wide range of future temperature and precipitation projections across the continguous United States (O'Dea et al. 2023, Joyce and Coulson 2020).

1. MRI-CGCM3 – least warm
2. HadGEM2-ES – hot
3. IPSL-CM5A-MR – dry
4. CNRM-CM5 – wet
5. NorESM1-M – middle-of-the-road

All forested FIA plots on lands managed by the Forest Service and BLM were included in this analysis, and within that set of plots mature and old-growth forest plots were identified using definitions and criteria applied in the mature and old-growth forest inventory report (USDA and USDI 2023). Only plots that met the RPA definition of forest land[2] were used in this analysis; thus, the extent of mature and old growth used in this analysis does not directly match the extent of the inventory from the initial mature and old-growth forest inventory report. Additionally, while the area of mature and old-growth forests changes over time in these projections, it was assumed that forests on lands managed by the Forest Service and BLM remained in forest use (even if the forest cover temporarily changed) for the life of the projections. Furthermore, because the projections were based on the FIA inventory, sampling error associated with inventory design is inherent in these projections, remained constant over time at 2020 levels for all variables projected, and is not shown explicitly in the figures, although the sampling error associated with individual realizations comprises a portion of the variability across model realizations.

Spatial Analysis of Historical, Current, and Future Conditions

The purpose of this analysis was to understand the amount and distribution of mature and old-growth forests exposed to various potential threats or conditions—and how that exposure has changed since recent historical times and might change in the future. The spatial analysis was conducted at the fireshed scale (250,000 acres). Firesheds are part of a national, nested spatial framework (the Fireshed Registry[3]) that divide the United States into similarly shaped and sized polygons to serve as analytical units for the assessment of wildfire risk and other natural resource management priorities and trends (Ager et al. 2021). Only the forested portions of lands managed by the Forest Service and

2 An international forest land definition that yields a slightly smaller forest land base than when using the FIA forest land definition because of its minimum height requirement (16.5 ft) that excludes some woodlands, primarily in the southwestern United States (Oswalt et al. 2019).

3 Fireshed Registry: https://www.arcgis.com/home/item.html?id=d4dc3690c18f4656b3f1595477c1b4c4

BLM within each fireshed were analyzed because those areas relate directly to the mature and old-growth forest inventory estimates (USDA and USDI 2023). Where the data allowed, recent historical conditions (the last two to three decades of the last century) were included. Early-century, mid-century, and end-century conditions were based on the most up-to-date monitoring data or modeled from various climate change scenarios. Results were represented as current area of inventoried mature and old-growth forests (based on FIA estimates at the fireshed scale) that spatially coincided with (were exposed to) potential threats or ecological/socioeconomic conditions. For this analysis, the term exposure is defined as the magnitude or degree of change in climate or other factors a species or system is likely to experience. Historical and future estimates of mature and old-growth forest (by fireshed) were not available for this initial analysis and exposure for those time periods was based on current amounts.

Exposure of mature and old-growth forests to moderate- to high-severity wildfire (Eidenshink et al. 2007) was analyzed using recently published datasets projecting wildfire risk in the forests of the contiguous United States under two different Coupled Model Intercomparison Project 6 (CMIP6) scenarios based on SSPs tied to RCPs used in CMIP5—SSP2-RCP4.5, and SSP5-RCP8.5 (Anderegg et al. 2022). Exposure to climate change was based on two metrics: extreme heat and decreased water availability to forest vegetation. Exposure to extreme heat was based on climate models for number of days in a year that exceed 90 °Fahrenheit (USDA Forest Service 2018). Climatic water deficit (CWD) was used as the metric for exposure to decreased water availability as it relates to drought stress on vegetation (Stephenson 1998). This dataset comprises modeled change in CWD estimated for the recent historical period (1970−1999), early-century (2000–2029), mid-century (2035–2064), and end-century (2070−2099) using output from MC2 dynamic global vegetation model (DGVM) output (EPA 2017). Climatic water deficit is calculated as the difference between potential evapotranspiration (PET) and actual evapotranspiration (AET). MC2 DGVM was calibrated for the contiguous United States, and PET and AET were output using climate data averaged from 17 GCMs. GCM data are from the Localized Constructed Analogs (LOCA) downscaled climate dataset (Pierce et al. 2014, 2023) and represent RCP8.5 climate change scenario. Each GCM drives a single MC2 simulation. Additional geospatial layers were used for analyzing current conditions and potential threats in the following section and are described (including data sources) in appendix 5.

Mature and Old Growth Condition Assessment

To better understand the multiple drivers and stressors that interact in ecosystems, the Terrestrial Condition Assessment (TCA) model framework (Cleland et al. 2017) was adapted to focus on potential threats and ecological conditions that could degrade areas with mature and old-growth forests. The TCA is designed to support assessments of ecological integrity as described in the 2012 Planning Rule (36 CFR 219, FSM 1921.02, FSH 1909.12). The TCA leverages

nationally consistent datasets to model ecological conditions related to stressors, disturbances, and vegetation conditions for landtype associations (Cleland et al. 2017, Anderson et al. 2021). Landtype associations (LTAs) are mapped units that represent landscape-scale ecosystems in the National Hierarchical Framework of Ecological Units (NHFEU, DeMeo et al. 2001, Nelson et al. 2015, Winthers et al. 2005). The TCA is supported through the Ecosystem Management Decision Support (EMDS) logic model, which allows incorporating information about relationships among the indicators and metrics TCA considers (Reynolds and Hessburg 2014). The TCA summarizes data into different metrics and measures that are evaluated for each LTA, producing continuous scores ranging from +1 (representing very good ecological conditions) to -1 (representing very poor ecological conditions). Metrics are aggregated to provide a score for each indicator, and indicator scores are aggregated to provide information on the ecological conditions of the analysis unit. The Forest Service runs the TCA annually.[4]

For this analysis, the TCA was modified to evaluate drivers and stressors most relevant to mature and old-growth forests under current ecological conditions, informed by historical trends and patterns to create the Mature and Old Growth (MOG) Condition Assessment (MOGCA). The modification required focusing on indicators relevant to forest ecosystems (such as dropping TCA indicators focused on grassland conditions), revising the model structure, and changing analysis units to align with the mature and old-growth forest inventory report. The mature and old-growth forest inventory report used firesheds polygons to display estimates of mature and old-growth forests (USDA and USDI 2023). However, firesheds were too large and ecologically diverse for a TCA-like analysis, so smaller units from the registry were used. The registry calls these smaller units "project areas," and they are approximately 25,000 acres in size. Within each analysis unit, ecological indicators and metrics were summarized only on forestlands managed by the Forest Service and BLM. Conditions were upscaled to firesheds using an area-weighted averaging approach of continuous scores, so that results could be related to the mature and old-growth forest inventory. The areas analyzed covered from 75.8 to 81.1 million acres of mature forest and 24.7 to 27.5 million acres of old-growth forest in the contiguous United States.

By adapting the TCA to focus on areas with mature and old-growth forests, the model provides a means to analyze stressors, disturbances, and potential threats both individually and in conjunction with one another. Refer to appendix 5 for more details on the MOGCA, including the modification process, model details, and specific datasets used.

4 (https://terrestrial-condition-assessment-usfs.hub.arcgis.com/)

Results

Fire

Fire, whether wildfire, Indigenous burning, or prescribed, is a dominant ecological disturbance in many forest ecosystems and can behave as a driver or stressor. Adverse effects from fire depend on the forest conditions, the severity and extent of the fire, and ultimately the forest condition following the fire as it relates to the social, economic, and cultural values the forest provided prior to (and after) burning. For example, forest visitors might avoid recently burned mature and old-growth forests, reducing economic benefits in those areas, and possibly increase recreation-associated overuse in unburned areas.

Information from the worksheets for the condition-based evaluation show how different ecosystems throughout Forest Service regions interact with fire as a threat or beneficial outcome (appendix 3). Pacific Northwest Region employees relayed that, when members of the public place existence value on certain species such as the iconic Douglas-fir, loss of this old growth tree due to fire inherently manifests as a negative social outcome. In reference to oak woodlands, employees from the Pacific Southwest Region took the same stance, "There are psychological and emotional benefits associated with the mere presence…that would be lost." Those existence values can vary in scale; sometimes interest is in a smaller area, whereas other vegetation types garner national attention. The threat to—or loss of—individual giant sequoias is of heightened concern across the country, garnering national media coverage when fires occur. Pacific Southwest Region employees went on to assert that, in addition to the tourism and income these trees provide to surrounding communities' economies, they are "…natural wonders treasured on an international scale and their loss is widely felt." Along a similar vein, uncharacteristic wildfire among ponderosa pine in the Rocky Mountain Region leads to loss of culturally modified trees, impacting Indigenous sense of place (Timmons et al. 2012).

Nationally, a total of 2,434 FIA plots on forested lands managed by the Forest Service and BLM experienced fire disturbance during the remeasurement period. An estimated 7.1 million acres of mature forest (8.8 percent of all mature forest), and an estimated 1.7 million acres of old-growth forest (5.6 percent of all old-growth forest) were disturbed by fire (approximately 710,000 and 170,000 acres per year, respectively). In forests disturbed by fire, there was a 2.6 million-acre decrease of mature forest (3.2 percent of all mature) and a 0.7 million-acre decrease of old-growth forest (2.2 percent of all old-growth forest). Forty-three percent of the fire disturbance in mature forest, and 31 percent in old-growth forest was in the low basal area loss category (less than 25 percent). Forests that experienced low basal area loss showed net gains in both mature and old-growth forest (figure 2). Thirty-three percent of the fire disturbance in mature forest, and 34 percent in old-growth forest, had severe (greater than or equal to 90 percent) basal area loss. Forests that experienced severe (equal to or greater than 90 percent) basal area loss showed statistically significant net losses of mature and old-growth forest between measurements. Net area changes varied for areas that experienced moderate (25–60 percent) and moderately severe

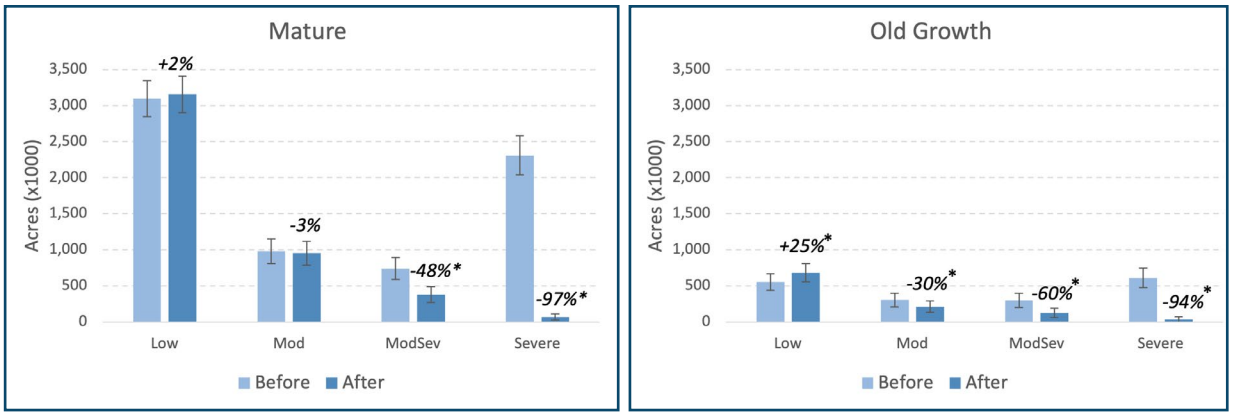


Figure 2.—Net changes (and 95-percent confidence intervals) in area of mature and old-growth forests that experienced fire disturbance over an average of 9 years from remeasured FIA plots (mostly 2000s to 2010s). Percentages represent net change by severity class and asterisks (*) indicate statistically significant net changes.

(60–90 percent) basal area loss from fire. Fire effects varied by Forest Service region (see appendix 6). No fires were recorded on plots in the Alaska Region. Losses of mature and old growth in forests that burned were greatest in fir/spruce/mountain hemlock, Douglas-fir, and lodgepole pine forest type groups (table 1).

The spatial analysis of historical, current, and future conditions examining exposure to fire was done at the fireshed scale for only the contiguous United States due to existing data limitations. Historically (1980–1999), less than half of inventoried older forests had high exposure to high risks (Anderegg et al. 2022) from moderate- to high-severity fire as defined by Monitoring Trends in Burn Severity (MTBS) classes (Eidenshink et al. 2007). During the first two decades of this century (2000–2019), between 70 and 80 percent have high exposure. Climate change projections predict an increase in this exposure to between 90 and 95

Table 1.—The five forest type groups with the most change in area of mature and old-growth forest in forests that experienced fire disturbance over an average 9-year period from remeasured FIA plots. Area and 95-percent confidence intervals (CI) are in thousands of acres; percents are the proportional change of the forest type group in the mature or old-growth class.

Forest Type Group	Mature Area Estimate	Mature 95%CI	Mature Percent	Old-Growth Area Estimate	Old-Growth 95%CI	Old-Growth Percent
Fir/spruce/mountain hemlock	-930	187	-6.6	-248	88	-3.5
Douglas-fir	-326	146	-3.5	-147	80	-4.2
Lodgepole pine	-375	123	-4.8	-122	72	-7.3
Piñon/juniper	-441	131	-3.0	-93	65	-1.0
Ponderosa pine	-258	130	-3.9	-81	73	-5.8

percent for mature forests and 95 and 100 percent for old-growth forests by the end of the century (2080–2099), depending on the socioeconomic and climate change scenario. The current threat from wildfire primarily exists in the West; however, climate change is predicted to expand the range of wildfires to most of the East by the end of the century. The northeast region is projected to remain at low exposure throughout this century (figure 3).

The largest percent change from historical conditions is projected to occur in the fir/spruce/mountain hemlock and Douglas-fir groups in the West, and the oak/hickory, loblolly/shortleaf, and maple/beech/birch groups in the East. The largest absolute modeled risk value change from historical conditions is projected to occur in the ponderosa pine, Douglas-fir, California mixed conifer, piñon/juniper, and the fir/spruce/mountain hemlock groups in the

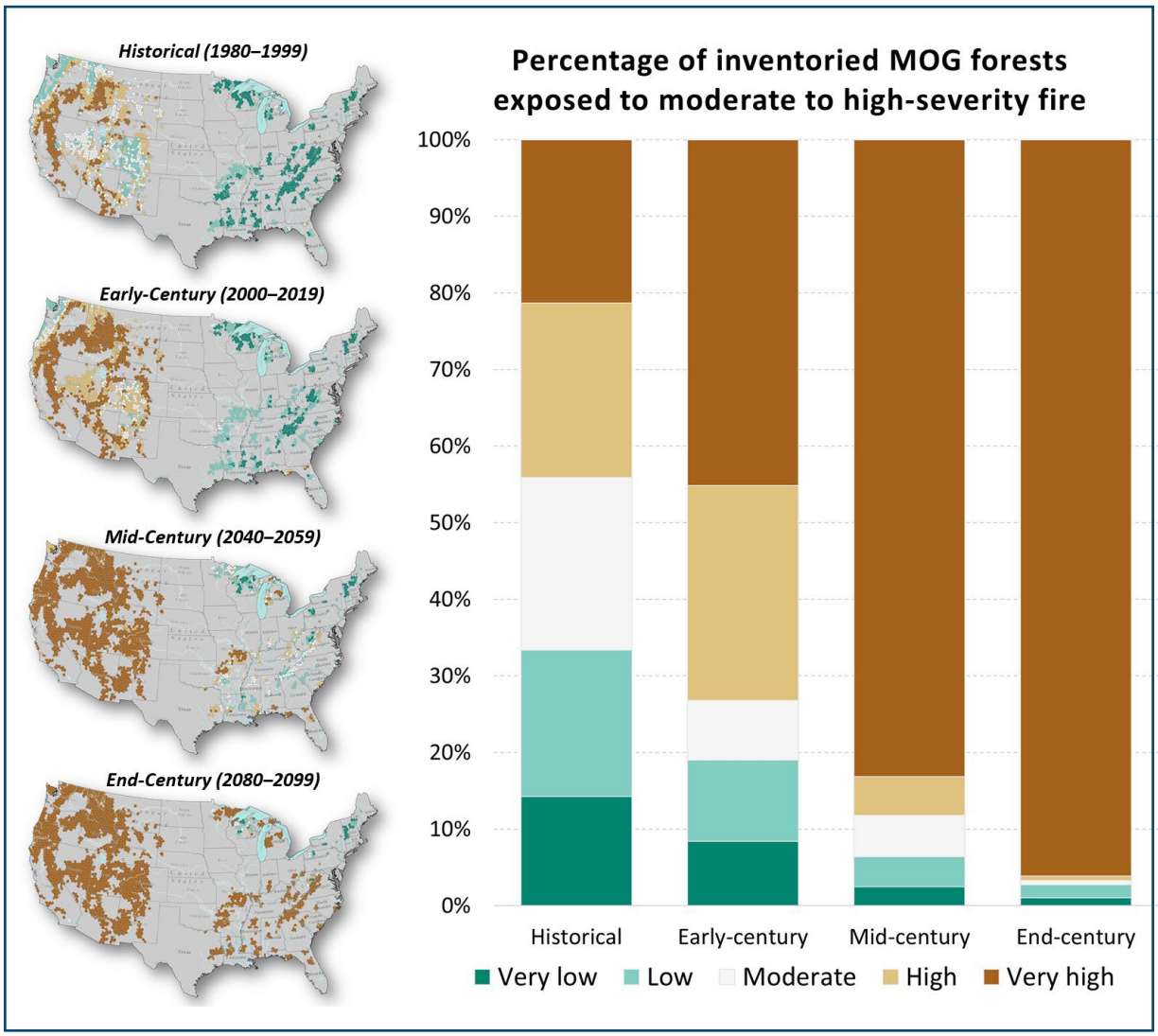


Figure 3.—Fireshed-scale exposure of inventoried mature and old-growth forests to moderate- to high-severity fire (SSP5-RCP8.5). The color scale represents exposure classes defined in table 2 below.

West, where wildfire-related mortality is a persistent stressor throughout the century. Absolute risk value changes were low in the East and forests in the New England States were persistently low in exposure to wildfire mortality under both scenarios.

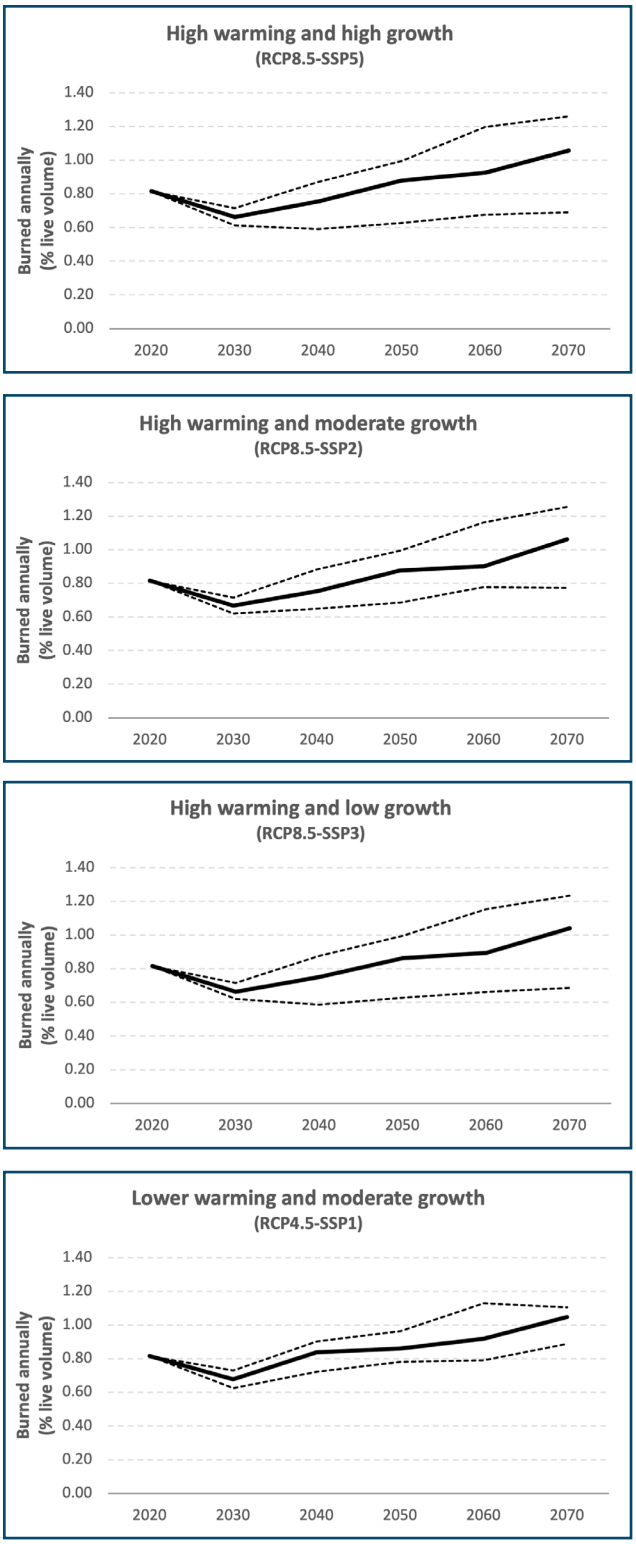
Increasing fire exposure means that an increasingly higher proportion of mature and old-growth forests will likely experience annual adverse effects from fire. Wildfires have increased in frequency and extent compared to the last two decades of the 20th century and account for most of the losses of mature and old-growth forests on lands managed by the Forest Service and BLM. An analysis of area burned by moderate- to high-severity wildfire was conducted using MTBS data (masked to Forest Service and BLM forestlands) for each map exposure class in figure 3 (combined across all firesheds) for the historical period (1980–1999) and early-century period (2000–2019) (see appendix 7). The area burned during the early-century period (2.5 million acres) was more than four times what was burned during the historical period (0.6 million acres) (table 2).

Based on FIA inventory data projections from the RPA Forest Dynamics Model, the proportion (by tree volume) of live mature and old-growth forest burned annually by moderate- to high-severity wildfire is projected to decrease in the first decade (2020–2030) then increases almost the same for all scenarios (figure 4). The initial decrease is likely due to large, high-severity fires in the Pacific Coast and South regions that occurred just prior to, or during, 2020 that are captured in the observed 2020 FIA numbers (see regional projections of area burned by moderate- and high-severity fires in appendix 8). The Forest Dynamics Model projects a return to earlier levels of wildfire by 2030 and increases over time after that.

The RPA Assessment (USDA Forest Service 2023) estimates that the largest increases in fire will occur disproportionately in the West among Douglas-fir, ponderosa pine, and piñon/juniper forests, as well as woodland hardwoods. In the East, fire-related mortality in the oak/hickory forest type group is projected to at least double (by volume) by 2070 and annual area of high-severity fires is projected to increase in all future scenarios (Costanza et al. 2023).

Table 2.—Proportion (total and averaged annually) of Forest Service and BLM forest burned by moderate- to high-severity wildfires. Historical data for Monitoring Trends in Burn Severity only extends back to 1984.

Exposure Class	Historical (1984–1999)		Early Century (2000–2019)	
	Total (%)	*Annual (%)*	*Total (%)*	*Annual (%)*
Very low	0.09	0.005	0.65	0.033
Low	0.46	0.023	1.4	0.07
Moderate	1.75	0.088	2.86	0.143
High	2.27	0.113	6.66	0.333
Very high	2.94	0.147	10.61	0.53



Fire Exclusion

Fire exclusion is the effort of deliberately excluding or preventing fire in an area, regardless of whether fire is natural or human caused. Federal fire-management policies which emphasized fire suppression rather than continuation of fire as an ecological and socio-cultural process began in the early-1900s (Pyne 1997). However, fire exclusion began long before the wildfire suppression era. Fire exclusion began centuries ago, with European visitations and colonization of forested regions, removing or displacing Indigenous populations. Removing Indigenous populations also removed frequent cultural burning that maintained nonforested areas and open forests and favored fire-adapted tree species. However, use of fire varied across Indigenous groups and regions and was not applied to all forested landscapes at the same levels. Historical, recorded observations remarked upon some of the changes in forested conditions that followed the cessation of this frequent (often annual) burning (figure 5).

There is an increasing body of research documenting the effects of prolongued fire exclusion in forest types that are characteristically maintained by frequent disturbance regimes (Hanberry et al. 2020, Reilly et al. 2021, Woodbridge et al. 2022, Brodie et al. 2023). There is general agreement among stakeholders that fire suppression and exclusion alters disturbance processes that eventually result in adverse outcomes, such as

Figure 4.—Observed (2020) and projected (2030–2070) trends in annual rates of tree mortality from moderate- to high-severity fires in mature and old-growth forests (mature and old growth combined) (CONUS). Solid lines reflect the median trend line of the median GCM (out of the five GCMs). The dashed lines represent the maximum and minimum values for the interquartile ranges (the middle 50 percent of the 100 replications) of projections across the five GCMs.

uncharacteristically severe fires or mesophication within forested systems. However, the magnitude and geography of fire exclusion, and stewardship response, is a topic of debate in both the eastern United States (for example, Oswald et al. 2020, Abrams and Nowacki 2020) and the West (for example, Hagmann et al. 2021, Gilhen-Baker et al. 2022).

The geographical and temporal extent of adverse outcomes from fire exclusion depends on the underlying fire regime and types of forests. For example, closed-canopy western hemlock, a fire-sensitive tree species, occur in cooler and moister climates with longer fire return intervals, whereas oak woodlands and pine forests occur in warmer and drier climates with shorter fire return intervals (Reilly et al. 2021). The effects of fire exclusion depend on the length of time exceeding the characteristic fire return interval, where longer exclusion (relative to the fire return interval) results in more uncharacteristic forest conditions.

Currently, some of the inventoried mature and old-growth forest FIA plots can be considered uncharacteristic due to fire exclusion. One example in western regions is the dense understory of Douglas-fir ingrowth in historical ponderosa pine forests. High tree densities of Douglas-fir in the understory

1 *"… the annual burning has been stopped, trees which were formerly confined to the river bottoms have gradually spread to the uplands. Small prairies situated just within the western edge of the forest have entirely disappeared within the memory of persons still living; the oak openings-open forests of large oaks through which the annual fires played without greatly injuring the full-grown trees-once the characteristic feature of these prairies, have disappeared. They are replaced by dense forests of oak…"*

2 *"The forest area has somewhat increased in the prairie region of the state since its first settlement and the consequent decrease of destructive prairie fires. The growth of trees has gradually spread from the bottom lands of the streams to the hills, and the oak forests upon the uplands have gradually encroached upon the prairie, losing their open, park-like character by the appearance of a young growth which has sprung up among the old trees."*

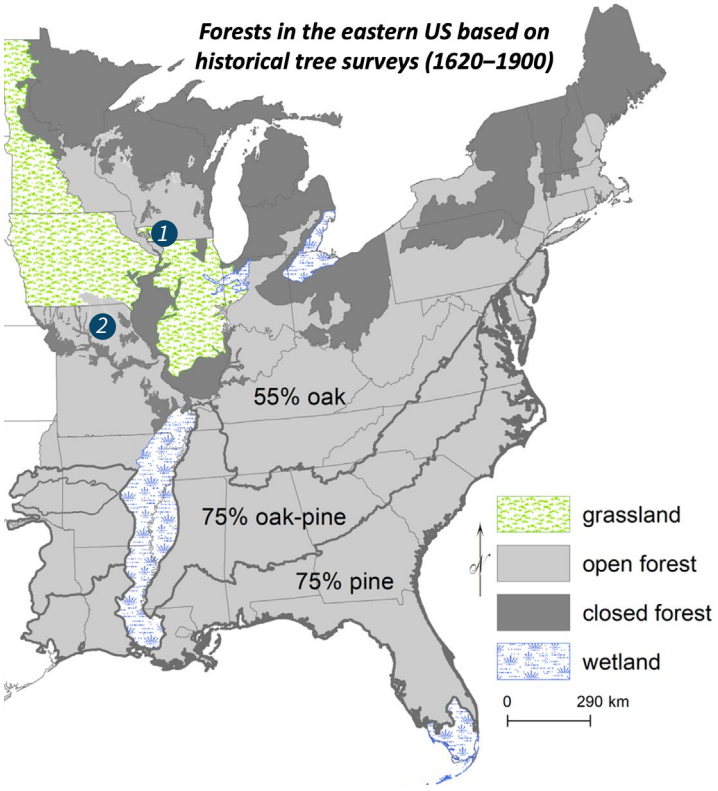


Figure 5.—Examples of written historical records illustrating the effects of frequent-fire exclusion on oak forests in the eastern United States from the "Report on the Forests of North America—Exclusive of Mexico" (Sargent 1884). Map courtesy of Brice Hanberry. Percentages represent areal extents of open forests within the delineated boundaries.

indicate the absence of fire in ponderosa pine forests (figure 6, figure 7, table 3, table 4). Small diameter Douglas-fir can suppress pine regeneration and may outcompete the large pines in the long term. Evidence indicates that high density of small-diameter trees leads to extreme fire behavior and loss of the larger, older trees when a fire does occur (for example, Fiedler and Arno 2015). Another example is red maple, a fire-sensitive, shade-tolerant species that flourishes in the absence of fire disturbance. One of the threats to mature or old-growth forests identified by eastern regions is mesophication, and its presence can be seen by the ingrowth of red maple, where high proportions of maple lead to the elimination of the oak over the long term (figure 8, figure 9, table 5, table 6). Uncharacteristically dense forests also display reduced resistance to insect pests, drought, and other environmental stressors (Vose et al. 2018).

Figure 6.—Photograph taken near Mt. Shasta, CA (circa 1949) with the caption stating "…it appears that the pine stand may gradually be replaced by a Douglas-fir, white fir stand." (Source: Wieslander Vegetation Type Mapping Collection, courtesy of the Marian Koshland Bioscience, Natural Resources & Public Health Library, University of California, Berkeley, http://guides.lib.berkeley.edu/Wieslander)

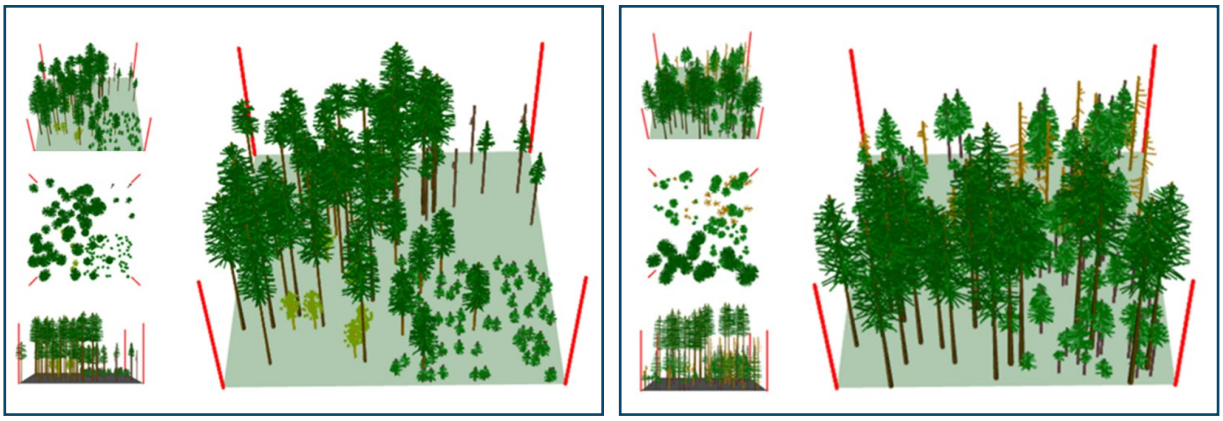


Figure 7.—Forest Vegetation Simulator images of FIA plots 40389335010690 (left) and 188772478020004 (right). Both plots are in the Intermountain Region. The mature and old-growth inventory identified some FIA plots classified as old-growth forest that supported uncharacteristic stand structure.

Table 3.—Tree diameter distributions (inches at breast height) from FIA plot 40389335010690 located in the Intermountain Region.

Common Name	1-5	5-10	10-15	15-20	20-25	25-30	30-40	40-50
Ponderosa pine	0	0	0	0	0	0	12	6
Douglas-fir	6	30	18	18	0	0	0	0

Table 4.—Tree diameter distributions (inches at breast height) from FIA plot 188772478020004 located in the Intermountain Region.

Common Name	1-5	5-10	10-15	15-20	20-25	25-30	30-40	40-50
Ponderosa pine	0	0	0	12	6	12	12	0
Douglas-fir	75	0	0	0	0	0	0	0
Lodgepole pine	0	0	6	0	0	0	0	0
Quaking aspen	0	6	0	0	0	0	0	0

Figure 8.—Photograph of an oak/hickory stand taken near Asheville, NC. Many of the large trees are chestnut oak, with the majority of the midstory made up of red maple. Tulip poplar, red maple, sassafras, and some smaller oaks are in the understory (photo courtesy of Margaret Woodbridge).

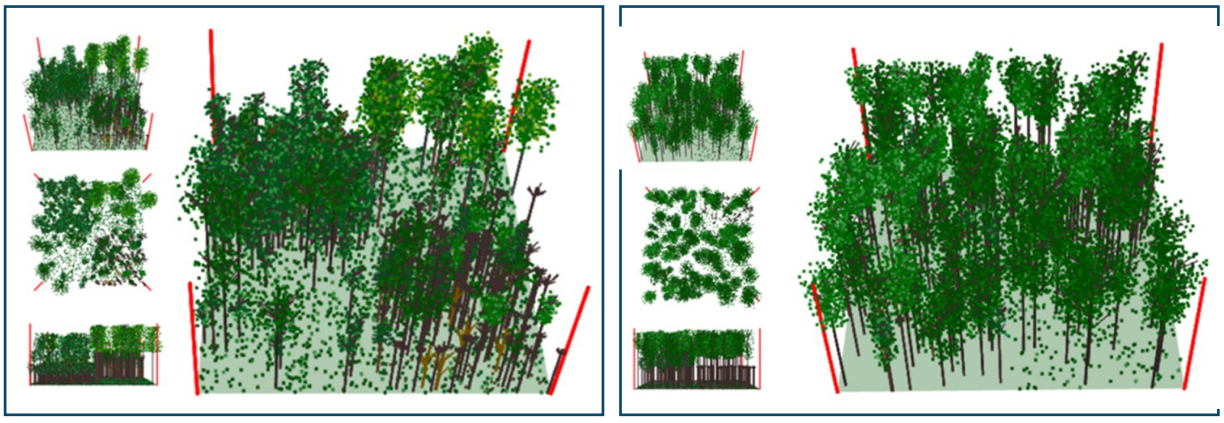


Figure 9.—Forest Vegetation Simulator images of FIA plots 480977014489998 (left) and 740834556290487 (right). Both plots are in the Southern Region. The mature and old-growth inventory identified some FIA plots classified as old-growth forest that show evidence of some of the threats identified in this report, especially mesophication and ingrowth of shade-tolerant species due to fire suppression.

Table 5.—Tree diameter distributions (inches at breast height) from FIA plot 480977014489998 located in the Southern Region.

Common Name	1-5	5-10	10-15	15-20	20-25	25-30	30-40	40-50
Chestnut oak	0	12	6	0	6	0	0	0
Scarlet oak	0	6	0	0	6	0	0	0
Mockernut hickory	0	0	0	0	0	0	0	0
Black gum	0	12	0	0	0	0	0	0
Eastern white pine	0	18	0	0	0	0	0	0
American basswood	0	6	6	0	0	0	0	0
Red maple	231	12	0	6	0	0	0	0

Table 6.—Tree diameter distributions (inches at breast height) from FIA plot 740834556290487 located in the Southern Region.

Common Name	1-5	5-10	10-15	15-20	20-25	25-30	30-40	40-50
Chestnut oak		0	12	18	6	0	0	0
Black oak	0	0	12	12	6	0	0	0
White oak	0	0	18	6	6	0	0	0
Black gum	0	12	0	0	0	0	0	0
Red maple	0	14	0	6	0	0	0	0

The following results were based on the MOGCA analysis (appendix 5). Areas where the time between recorded wildfire (going back to 1923 and including escaped prescribed burns) has exceeded historical mean fire return intervals were considered as "fire deficit" for this analysis. The spatial scale of this analysis was at the project area scale for the contiguous United States.

About 30 percent of mature forests currently have very low exposure to this threat, with smaller amounts in low exposure (16 percent), moderate exposure (18 percent), high exposure (16 percent), and very high exposure (20 percent). Mature forest types with the highest exposure were dominated by the fir/spruce/mountain hemlock, Douglas-fir, and ponderosa pine forest types. About 37 percent of old-growth forests currently have very low exposure to this threat, low exposure (18 percent), moderate exposure (20 percent), high exposure

(14 percent), and very high exposure (11 percent). The extent of Federal forest demonstrating fire deficits were highest (ranked by proportion of forest type group with high to very high deficits) in loblolly/shortleaf pine (95 percent), oak/hickory (87 percent), ponderosa pine (68 percent), Douglas-fir (37 percent), and piñon/juniper (31 percent) (figure 10).

While the degree of fire exclusion varies by forest type, certain conclusions can be drawn. Mature and old-growth forest types which historically experienced frequent fire exhibit dramatic increases in stand density, surface fuel loading, and species makeup. In fire-infrequent environments, certain fire-sensitive tree species have expanded in range and density which may increase fire risk and future fire severity. Increased vegetation density can also result in increased competition for site moisture and nutrients, resulting in stressed vegetation and the inability of the tree's natural defense to ward off insect attacks and mitigate disease infections. Forest development into uncharacteristic structure has raised the likelihood of high-severity fire in some forest systems and the incidence of insects and disease.

Historical contexts are factors in the legacy of fire exclusion and the susceptibility to adverse effects that follows. It has derived not only from direct suppression efforts but also removing Indigenous people from their

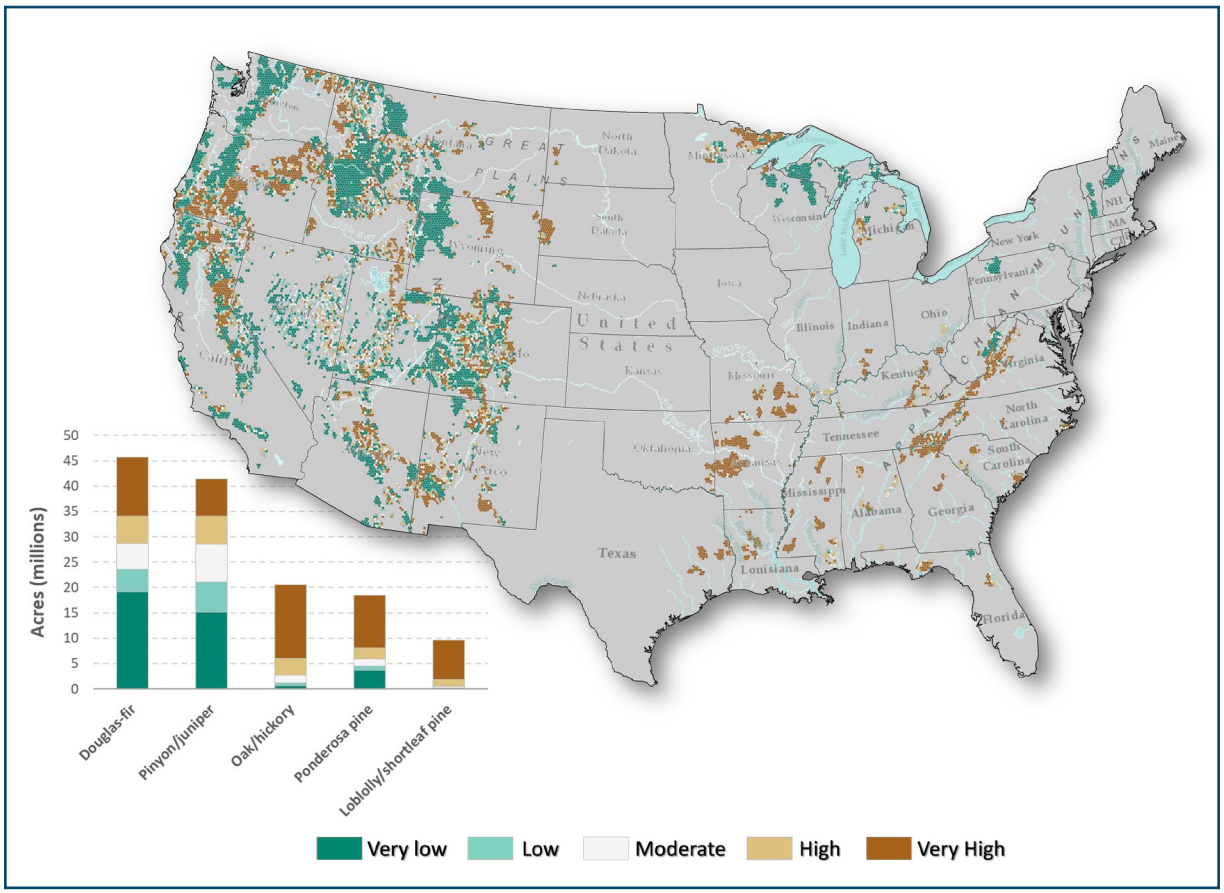


Figure 10.—Spatial patterns at the project area scale and area estimates (with 95-percent confidence intervals) of inventoried mature and old-growth forests exposed to wildfire threats based on fire deficit.

lands and prohibiting their cultural burning practices. Those actions resulted in negative ecological and social outcomes. Cultural burning promoted the Nation's mature and old-growth forest characteristics for centuries and is an important cultural practice (Long et al. 2021; Abrams and Nowacki 2015, 2020; Delcourt and Delcourt 1997). The frequency and extent of fires attributed to Indigenous burning practices on fire-forest processes in some regions is debated—some contest it was historically less than currently attributed (Matlack 2013, Oswald et al. 2020, Tulowiecki et al. 2023).

Insects and Disease

Tree mortality from endemic populations of native insects and tree diseases sometimes results in substantial loss of mature and old-growth forest stands. In contrast, nonnative insects and disease have caused extensive mortality of dominant overstory trees in several areas, sometimes moving mature and old-growth forests to earlier stages of forest development. Conditions that increase the vulnerability of forests to threats from both native and nonnative forest insects and disease can include increased frequency of heat and drought owing to climate change, damaging wind or ice storms due to climate change, and unnaturally high tree densities resulting from fire exclusion in frequent-fire forest types. Even when mature and old-growth forests remain after infestations, the changes to these forests may have substantial negative social, cultural, and economic impacts.

Nationally, a total of 5,177 FIA plots on forested lands managed by the Forest Service and BLM experienced insect or disease disturbance during the remeasurement period. An estimated 15.7 million acres of mature forest (19 percent of all mature forest) and 5.7 million acres of old-growth forest (18 percent of all old-growth forest) were disturbed by insects and disease (both native and nonnative species). In forests disturbed by insects and disease, there was a 1.9 million-acre (2.3 percent) decrease of mature forest and a 182,000-acre (0.6 percent) decrease of old-growth forest. The severity of the effects was mostly low (less than 25 percent basal area loss) in 67 percent of mature and 73 percent of old-growth plots. Results suggest no significant change in mature forest area but a significant net gain in old-growth area, likely owing to increases in dead tree components that are elements of some old growth definitions. About 33 percent of mature and 27 percent of old growth plots affected by insects or disease with greater than 25 percent basal area loss had statistically significant net losses—mature and old growth representing an adverse outcome. In general, the changes associated with insects and disease varied based on a range of conditions. Depending on which region the disturbance occurred in, and whether the stand was mature or old growth, the area estimates before and after occurrence varied substantially (appendix 9). Losses of mature and old growth in forests that experienced insects and disease disturbance were greatest in lodgepole pine, fir/spruce/mountain hemlock, and other western softwoods (primarily limber and whitebark pine) forest type groups (table 7).

Current effects from insects and disease were highest (ranked by proportion of forest type group with high to very high threat) in lodgepole pine (81 percent), fir/

Table 7.—The six forest type groups with the most change in area of mature and old-growth forest in forests that experienced insect and disease disturbance over an average 9-year period from remeasured FIA plots. Area and 95-percent confidence intervals (CI) are in thousands of acres; percents are the proportional change of the forest type group in the mature or old growth class.

Forest Type Group	Mature Area Estimate	Mature 95% CI	Mature Percent	Old-Growth Area Estimate	Old-Growth 95% CI	Old-Growth Percent
Lodgepole pine	-706	202	-9	-295	122	-17.6
Fir/spruce/ mountain hemlock	-812	218	-5.8	-110	160	-1.5
Other western softwoods	-188	105	-8.4	-78	63	-11.7
Aspen/birch	69	121	2	-59	88	-4.6
Piñon juniper	-144	93	-1	87	69	1
Douglas-fir	-122	172	-1.3	123	94	3.5

spruce/mountain hemlock (63 percent), ponderosa pine (63 percent), Douglas-fir (61 percent), and piñon/juniper (56 percent). Tree-killing insects and disease are characteristic elements of high-integrity mature and old-growth forests and can result in positive outcomes, as indicated by a net gain of old growth in the plot data when disturbance magnitudes were low (figure 11).

Nonnative insects and disease may impact mature and old-growth forests with a variety of negative social, cultural, and economic outcomes. Even when mature and old-growth forests persist after substantial tree mortality, impacts may be substantial. For example, specialists in the Southern Region explained how hemlock woolly adelgid can cause hemlock mortality in southeast maple/beech/birch forests. The loss of hemlock creates substantial changes in the forest composition and structural conditions. In conjunction with diminished tree species diversity, mortality from the adelgid diminishes scenic quality.

In addition to aesthetics and recreation, the economic value of mature and old-growth forests also includes consumptive uses. When nonnative pathogens lead to oak loss, specialists in the Southern Region went on to say, decreases in mast availability for wildlife result in diminished deer and turkey hunting opportunities. Tree harvest also provides revenue and, when insects and disease lead to loss of the economically valuable white ash, economic revenue declines.

Cultural values can be realized through both consumptive and nonconsumptive uses. Historically, many Tribes derived large portions of their food from the flour made by milling the acorns of tanoak. Loss of tanoak from Sudden Oak Death (*Phytophthora ramorum*) impacts the

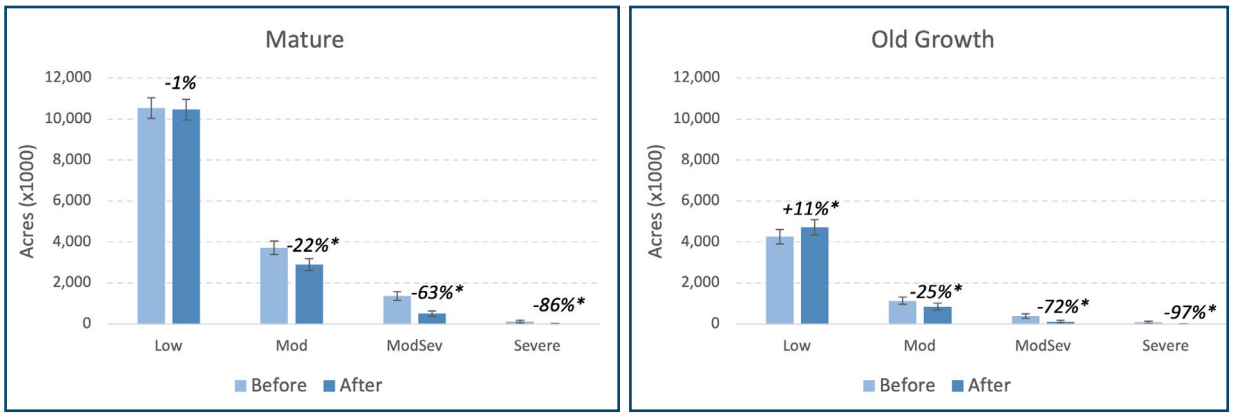


Figure 11.—Net changes (and 95-percent confidence intervals) in area of mature and old-growth forests from insect/disease disturbance over an average of 9 years from remeasured FIA plots (mostly 2000s to 2010s). Percentages represent net change by severity class and asterisks (*) indicate statistically significant net changes.

ability of Tribes to sustain traditional lifeways (Ortiz 2008, Halpern et al. 2022).

Stressors can interact with each other to create or worsen threats. In the Pacific Northwest, tanoak killed by insects and disease lead to increased fire hazard—especially in the wildland-urban interface. In California's subalpine fir, many of the root diseases are exacerbated by management activities that result in wounded host trees.

Similar to other ecological disturbances, tree-killing insects and tree pathogens occur at low to modest levels in all forests increasing ecological diversity, species diversity, and structural diversity. Regional specialists identified native forest insects and disease pathogens as the primary threat to only a few forest ecosystems. Several eastern and western pine and spruce forest types experience substantial overstory tree mortality, sufficient to change from mature or old growth to an earlier stage of development when forest conditions and climate combine to form epidemic insect outbreaks.

Most western coniferous forests experience bark-beetle (for example, Douglas-fir beetle, mountain pine beetle, spruce beetle) outbreaks that threaten mature and old-growth forests. Mountain pine beetle outbreaks have affected millions of acres of forest throughout the West in Oregon, Colorado, Montana, and Wyoming over multiple decades. Uncharacteristically high tree density and homogeneity combined with drought and repeated mild winters (which are increasingly likely with climate change) represent the conditions leading bark beetles from endemic to threatening conditions.

Spatial analyses examining exposure showed that recent outbreaks (2012–2021) contributing to tree mortality events have been concentrated in the California mixed conifer, ponderosa pine, and fir/spruce/mountain hemlock forest types. In total, 392 project areas had tree mortality from insects and disease across a large enough extent to be classified as poor or very poor, representing just over 4 percent of the federally managed

forested land considered in this analysis, or about 6.7 million acres (appendix 5). More than 90 percent of project areas representing approximately 149 million acres of federally managed forested land had very small areas or no significant tree mortality observed between 2012 and 2021, which resulted in higher modelled scores representing good and very good ecological conditions. Some of these areas have had significant amounts of tree mortality in the preceding time periods (prior to 2012).

Based on the MOGCA analysis, about 83 percent of mature forests currently have very low exposure to tree mortality events caused by insects or disease, low exposure (10 percent), moderate exposure (4 percent), high exposure (2 percent), and very high exposure (1 percent) (figure 12). Mature forest types with the highest exposure were dominated by the fir/spruce/mountain hemlock, Douglas-fir, and ponderosa pine forest types. About 85 percent of old-growth forests had very low exposure to this threat, low exposure (9 percent), moderate exposure (4 percent), high exposure (1 percent), and very high exposure (1 percent) (figure 12). Old-growth forest types with the highest exposure were dominated by the fir/spruce/mountain hemlock, Douglas-fir, and ponderosa pine forest types.

Eastern oak forests represent a clear example of changes in land use history

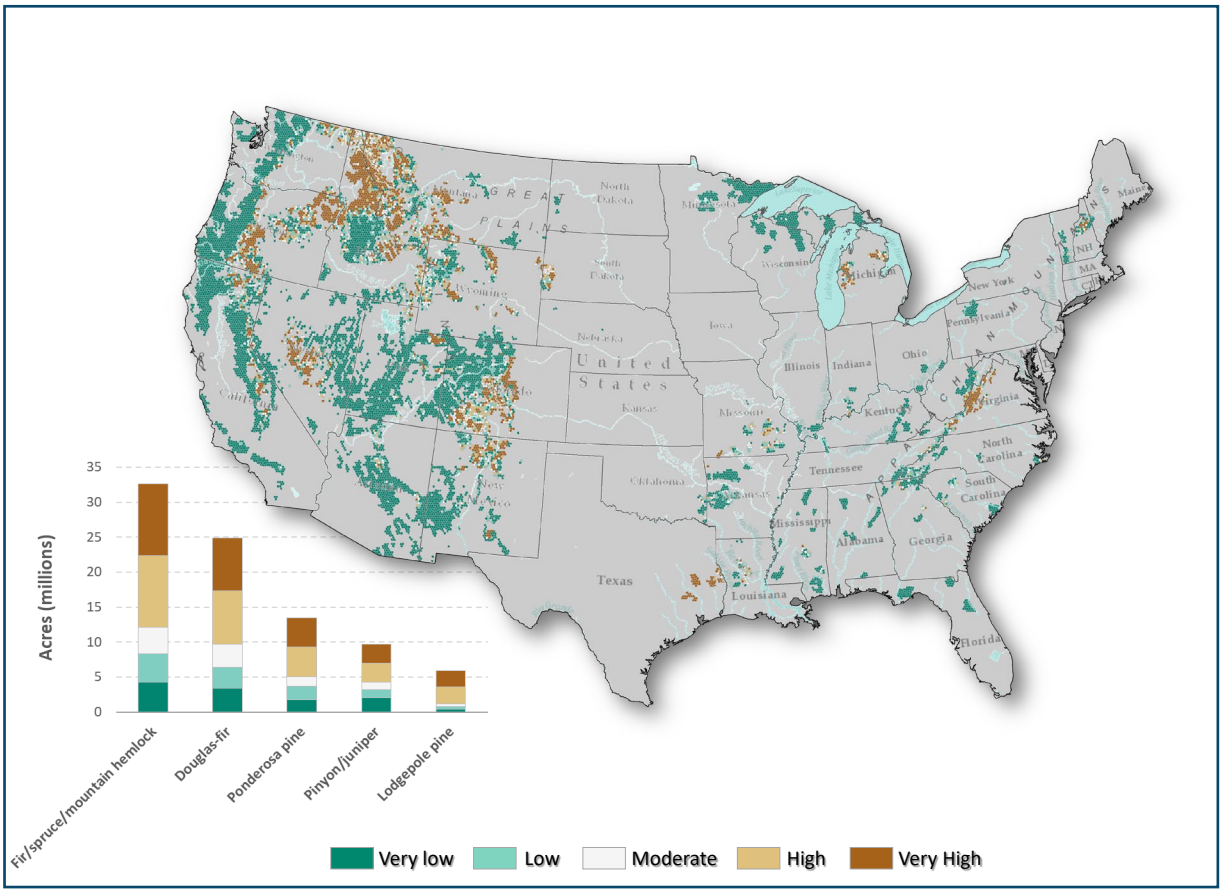


Figure 12.—Map depicting spatial patterns at the project area scale of inventoried mature and old-growth forests exposed to threats from insects and disease.

interacting with native and nonnative tree diseases threatening mature and old-growth forest types under particular and potentially widespread conditions. Oak forests that become uncharacteristically dense with shade-tolerant species, such as maple, in the absence of intermediate disturbance such as fire are also vulnerable to oak decline, a complex set of factors that kill large oak and therefore threaten mature and old-growth forests.

While native insects are most threatening to pine and spruce forests, and generally under uncharacteristic tree density for frequent-fire forest types, nonnative insects and pathogens threaten both deciduous and coniferous mature and old-growth forests—and the threat is rarely associated specifically with stand structure. Recent insect-caused mortality appears to be far outside what has been documented since Euro-American settlement and is likely related to climate change (Vose et al. 2018). With nonnative insects, it is more than just climate change. Increased global trade and transportation of vectors have increased the likelihood of nonnative insects finding novel suitable environments (Hulme 2009).

Extreme Weather Events

Threats from extreme weather and abiotic events are much more isolated and their impacts are highly dependent on the ecosystem. Ice storms, windstorms (including hurricanes and tornados), flooding, and landslides are some examples. Based on FIA plot remeasurements since the start of this century, extreme weather events have not accounted for much change in the areal extent of mature and old-growth forests. Yet, the episodic nature of these events does not make them less important to consider. The occurrence of extreme weather events can have adverse effects, especially in areas where mature and old-growth forests are rare, highly fragmented, and isolated. Extreme weather events will become more frequent with climate change, driving changes in forest structure and function that can make mature and old-growth forests more susceptible to other potential threats across large landscapes (Vose et al. 2018).

Nationally, a total of 3,066 FIA plots on forested lands managed by the Forest Service and BLM experienced weather-related disturbances including weather damage, ice, flooding, wind (hurricanes and tornados), drought, or avalanches during the remeasurement period. An estimated 1.1 million acres of mature forest (1.4 percent of all mature forest) and an estimated 0.6 million acres of old-growth forest (1.8 percent of all old growth) were disturbed by weather between remeasurements. In forests disturbed by weather, there was an 83,000-acre (0.1 percent) decrease of mature forest and a 10,000-acre (0.03 percent) increase of old-growth forest; neither change was statistically significant. Eighty percent of the weather disturbance in mature forest, and 91 percent in old-growth forest, was in the low severity basal area loss category. Forests that experienced low (less than 25 percent basal area loss) weather disturbance gained mature and old-growth forest area, likely owing to creation of snags and down wood (figure 13). Forests affected by severe weather (greater than or equal to 90 percent basal area loss) experienced losses of 1.3 percent of mature and 1.5 percent of old-

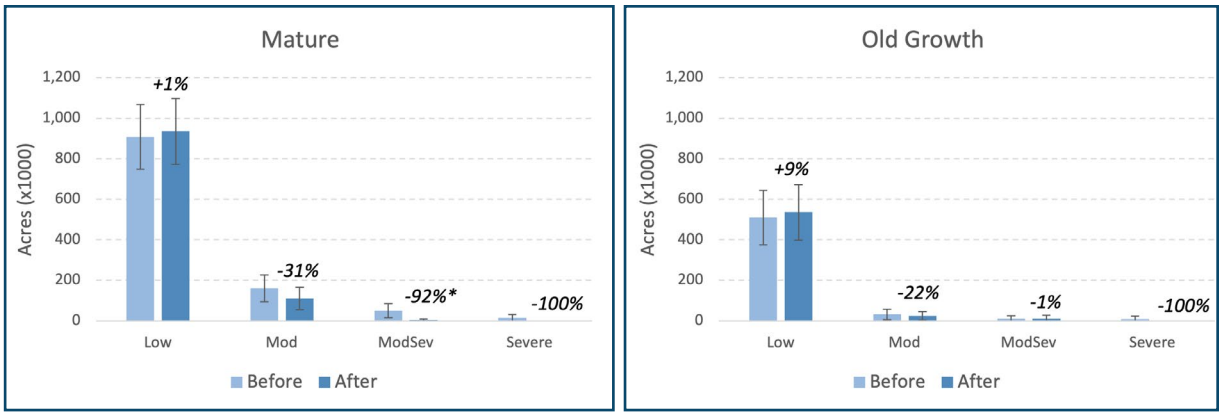


Figure 13.—Net changes (and 95-percent confidence intervals) in area of mature and old-growth forests that experienced weather disturbance over an average of 9 years from remeasured FIA plots (mostly 2000s to 2010s). Percentages represent net change by severity class and asterisks (*) indicate statistically significant net changes.

growth forests. Moderate (25–60 percent basal area loss) to moderately severe weather (60–90 percent basal area loss) corresponded with intermediate levels of net declines for both mature and old-growth forests. Weather effects varied by region (see appendix 10).

The area classified as being affected by weather (meeting FIA disturbance thresholds) was sufficiently small that the analysis by forest type group suggested no significant changes at the 95-percent confidence level (table 8).

Extreme weather usually disturbs mature and old-growth forests in small patches or damages and kills limited numbers of large trees, rarely transforming it to earlier developmental stages. East coast hurricanes represent an exception; individual storms can rapidly transform

Table 8.—The five forest type groups with the most change in area of mature and old-growth forest due to weather over an average 9-year period. Area and 95-percent confidence intervals are in thousands of acres; percents are the proportional change of the forest type group in the mature or old growth class.

Forest Type Group	Mature Area Estimate	Mature 95% CI	Mature Percent	Old-Growth Area Estimate	Old-Growth 95% CI	Old-Growth Percent
Fir/spruce/ mountain hemlock	-32.5	63.3	-0.2	-3.9	32.6	-0.1
California mixed conifer	-23.6	32.7	-0.8	4.1	20.4	0.4
Western oaks	-16.1	20.5	-1.8			
Oak hickory	-14.3	18.7	-0.2			
Lodgepole pine	-13.9	34.9	-0.2	-5.2	25.3	-0.3

mature and old-growth forests over large areas. While storm events can extend over a large swath, the adverse impacts are often patchy. Similarly, long-track tornados can produce large swaths of forest loss, such as the 1974 tornado outbreak in the Ohio Valley (Corfidi et al. 2010). Since 2000, weather caused the biggest net loss (17,000 acres) of mature and old-growth forests in the Southern Region; the region where hurricanes are most common. Nationally, about 100,000 acres (0.1 percent) of mature forest and 27,000 acres (0.09 percent) of old growth were lost over the same time period. Weather impacts were of low severity (less than 25 percent basal area mortality) in 80 percent of mature and 91 percent of old-growth forests and even resulted in gains in old-growth forest. About 1.3 percent of mature and 1.5 percent of old-growth forests had net area losses. Given the small sample size, there were no significant changes at the 95-percent confidence level, but the data suggest that the largest losses due to weather were in the fir/spruce/mountain hemlock, California mixed conifer, lodgepole pine, western oak, and oak/hickory forest type groups. Despite the fine-grain spatial pattern of tree mortality and limited loss of mature and old-growth forests, extreme weather events pose real threats to many social, cultural, and economic values (figure 14).

Disturbance by extreme weather events is inextricably linked to climate change (Marvel et al. 2023). While ice storms, windstorms, flooding, and similar extreme events have always disturbed forests, climate change is known to increase both the frequency and intensity of extreme weather events. Also, these events are becoming more erratic and extreme due to climate change. In recent years, Caribbean tropical hardwood forests across Puerto Rico, for example,

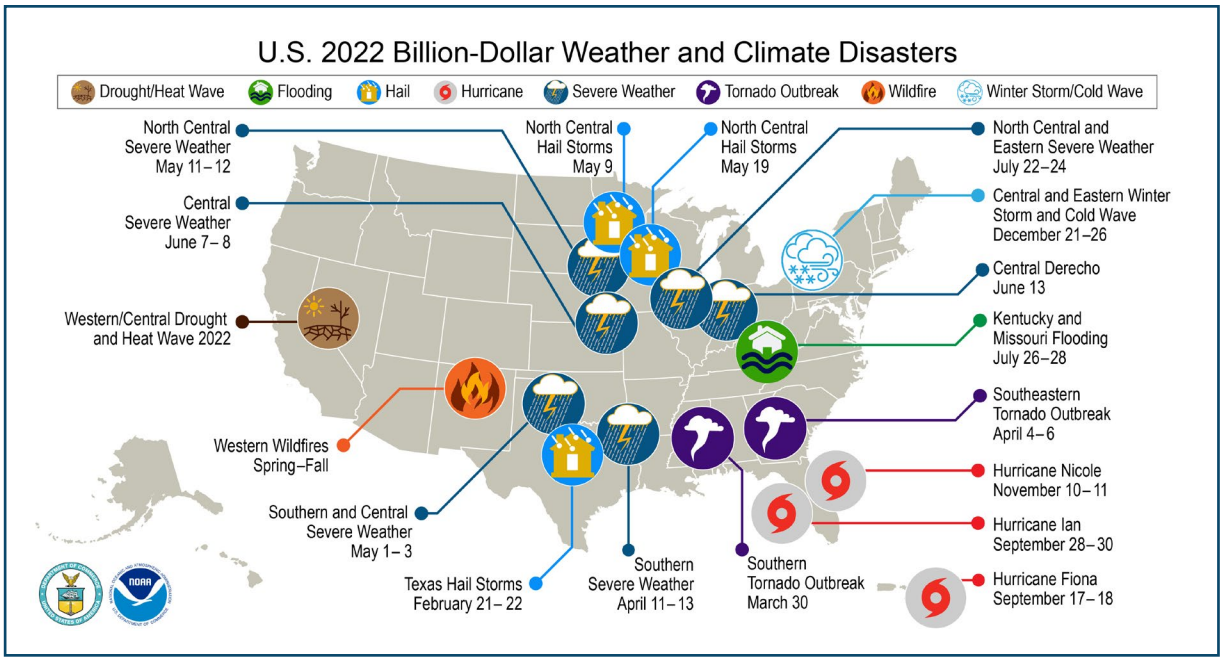


Figure 14.—A graphical representation of recent extreme weather events in the United States (https://www.noaa.gov/news/record-drought-gripped-much-of-us-in-2022).

experienced the most extreme drought, wind, and precipitation events since at least the 1950s (Herrera and Ault 2017, Keellings and Alaya 2019), which in the short term reduced forest height and cover, increased tree mortality, and increased some invasive species biomass (Helmer et al. 2023, Vargas-Gutierrez et al. 2023). Longer-term and compound effects of these and other climate stressors of tropical forests, like atmospheric water stress (Bauman et al. 2022), are not well known. Concern exists about whether cyclonic storms might allow greater establishment of nonnative or nonnative invasive species that might affect the structure and species composition of mature and old-growth forest, which in turn affect ecosystem properties and socioeconomic and cultural values (USDA Forest Service 2023).

Climate Change

Climate change is a complex stressor, interacting with and exacerbating other stressors or threats (fires, insects, etc.)—consequences will take different forms in different regions and forest types (USDA Forest Service 2023). In virtually every climate scenario, the ecosystem services and values enjoyed by various communities are likely to change (Voggesser et al. 2013, Weiskopf et al. 2020, Domke et al. 2023, McElwee et al. 2023).

The most recent year (2023) marks the hottest year, globally, on record.[5] Historically (1970–1999), about one-third (32 percent) of the inventoried mature and old-growth forests in the contiguous United States rarely exceeded 90 °Fahrenheit in any given year (less than 1 day per year; very low exposure), about 36 percent had low exposure (1 day to 1 week per year), 21 percent had moderate exposure (1 week to 1 month per year), 8 percent had high exposure (1–2 months per year), and 3 percent were exposed to 2 or more months per year (very high exposure). Currently (2010–2039), from 82 to 84 percent of mature and old-growth forests are exposed to temperatures exceeding 90 °Fahrenheit for at least 1 day during any given year and exposure to 2 or more months has more than doubled (6.9–7.5 percent). Depending on the atmospheric warming scenario (RCP4.5 and 8.5), from 14 to 33 percent of inventoried mature and old-growth forests may experience 2 or more months of extreme heat by the end of this century (2070–2099). Under RCP8.5, less than 1 percent will *not* experience less than 1 day per year of extreme heat (figure 15).

The time series maps below illustrate predicted changes in climate exposure and were based on the spatial analysis of historical, current, and future conditions. The following figure represents the number of days in a year that exceed 90 °Fahrenheit (figure 15). Each map represents a three-decade climate normal, beginning with the last three decades of last century. This climate metric identifies exposure to high temperatures, such as heat domes, which can have direct adverse effects on mature and old-growth forests (Still et al. 2023), but can also highlight drought effects, including higher metabolic respiration and more extended periods with closed stomata and increasing stress on trees (Klein et al. 2022).

5 See https://www.noaa.gov/news/2023-was-worlds-warmest-year-on-record-by-far and https://climate.copernicus.eu/global-climate-highlights-2023

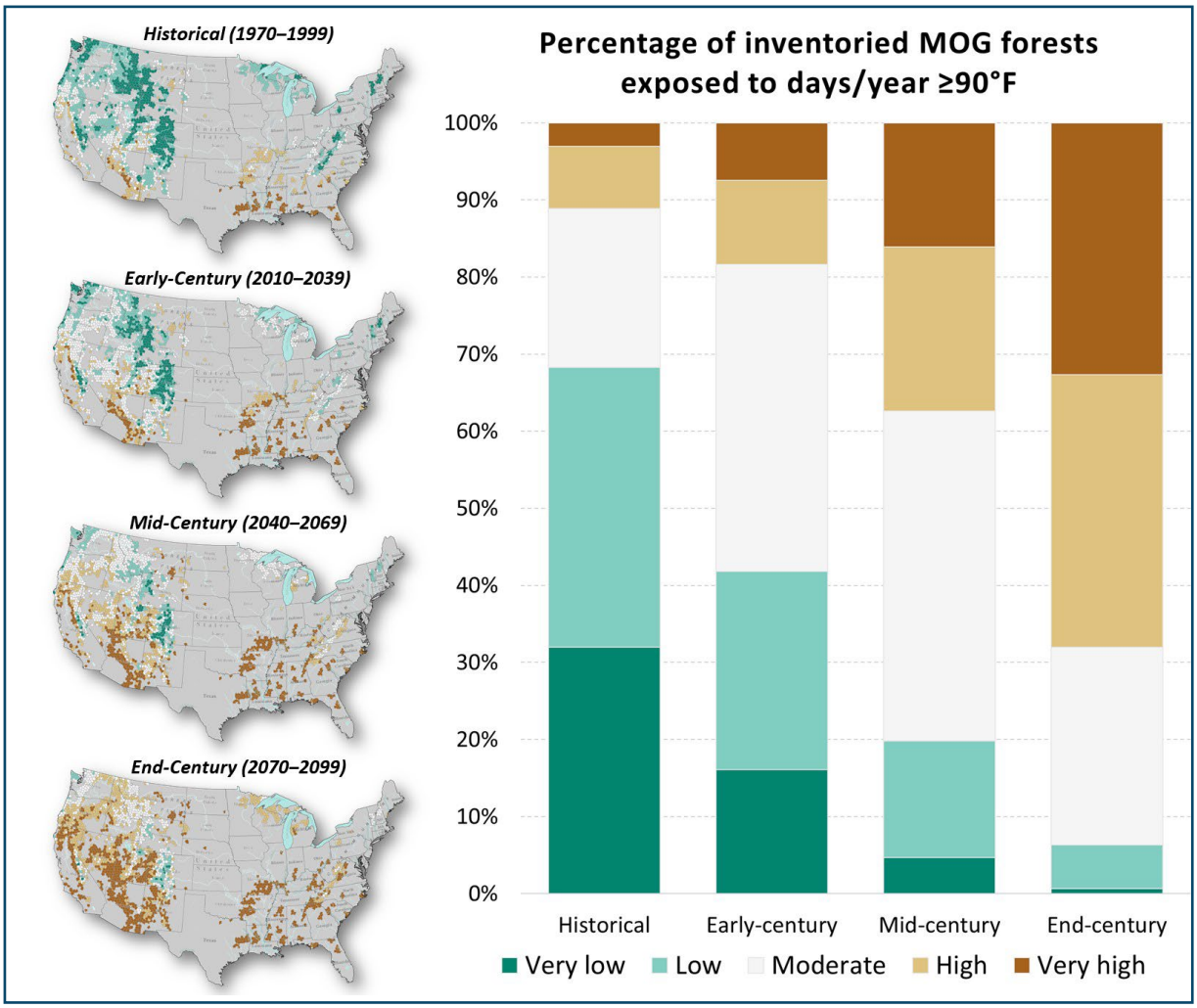


Figure 15.—Fireshed-scale exposure of inventoried mature and old-growth forests to extreme heat (days/year ≥90 °F (RCP8.5)).

The highest absolute changes (from historical levels) are predicted to occur (from highest to lowest) in the piñon/juniper, oak/hickory, loblolly/shortleaf pine, woodland hardwoods, and longleaf/slash pine forest types. The highest percentage change (from historical levels) is predicted to occur (from highest to lowest) in the fir/spruce/mountain hemlock, Douglas-fir, piñon/juniper, lodgepole pine, and aspen/birch types.

Higher temperatures are expected to cause changes in the distribution and abundance of dominant forest species, with heat-tolerant species becoming more competitive. In forests, hotter temperatures will accelerate evapotranspiration as soils dry faster and as vegetation takes up water earlier and faster during the growing season.

Geographically extensive and long-duration drought conditions across the United States set several records in 2022 (NOAA). Higher temperatures result in higher levels of climatic water deficit, where available soil moisture is less than required for normal growth and results in tree stress (Vose et al. 2016). Climatic water deficit was used to identify

firesheds where mature and old-growth forests might experience drought, or moisture stress, depending on the type and condition of the forest. The amount of mature forest area that historically (1970–1999) had very low exposure to drought has already decreased by about half and old-growth forest by about 43 percent (based on RCP8.5 models). By the end of the century (2070–2099) less than 1 percent of inventoried mature and old-growth forests are projected to have very low exposure. On the other end of the exposure spectrum, the amount of mature forest area that historically had very high exposure to drought has already increased by a factor of 1.9 and old growth by a factor of 2.7 (RCP8.5 models). By the end of the century, these exposures are projected to increase from historical values by factors of 18.0 and 14.1, respectively.

The time series maps illustrate how climatic water deficit has already changed and might change into the future (figure 16). This climate metric correlates well with several effects related to drought. Each map below represents a three-decade climate normal, beginning with the last three decades of last century. Drought sensitivity varies by forest type

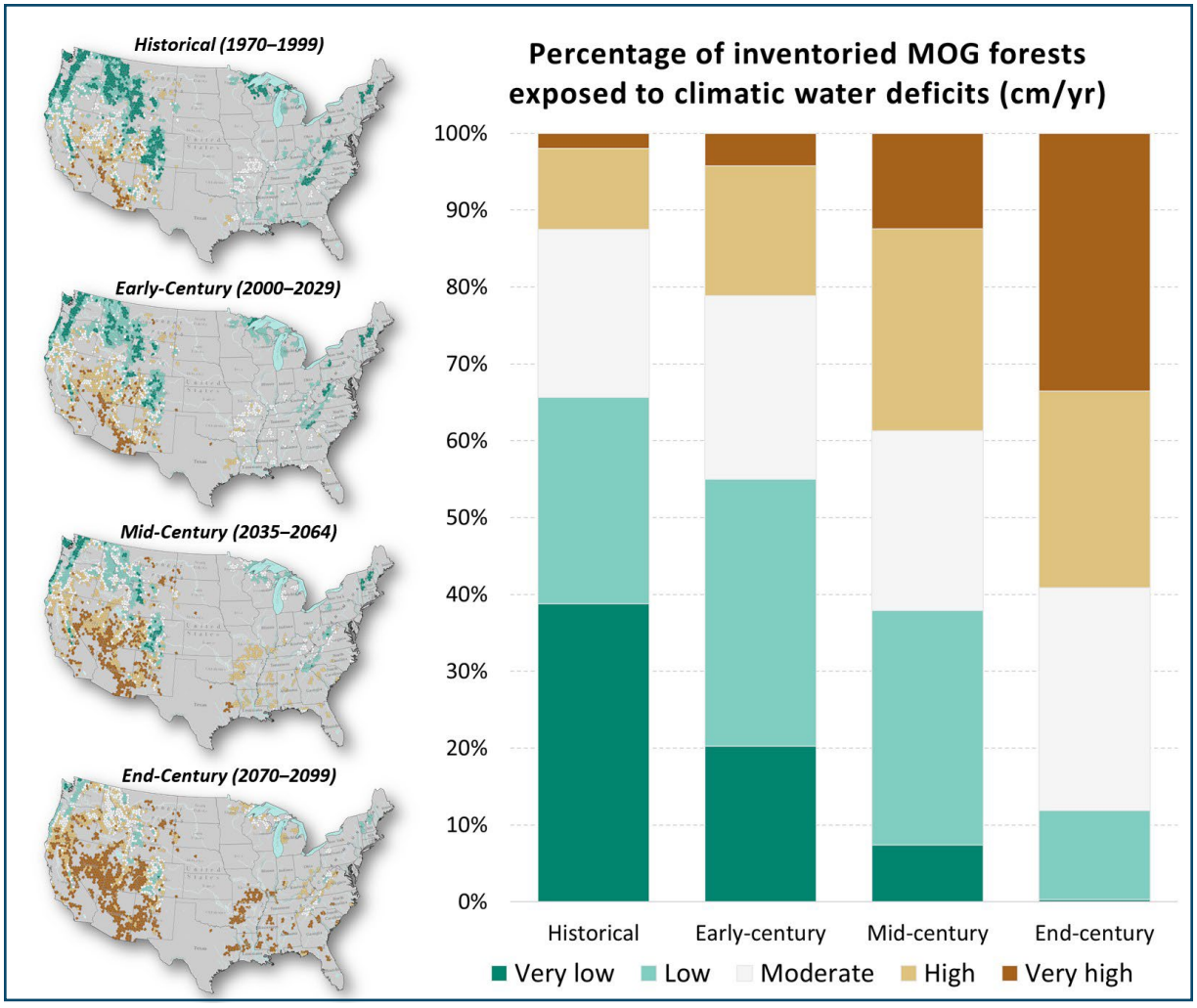


Figure 16.—Fireshed-scale exposure of inventoried mature and old-growth forests to climatic water deficits (RCP8.5).

and environmental factors such as, but not limited to, elevation, latitude, and topography.

The largest percent change from historical conditions is predicted to occur in the fir/spruce/mountain hemlock, Douglas-fir, and lodgepole groups in the West, and the maple/beech/birch and oak/hickory groups in the East. The largest absolute change from historical conditions is predicted to occur in the piñon/juniper group in the West and the loblolly/shortleaf pine, oak/hickory, woodland hardwoods, and longleaf/slash pine groups in the East.

According to the most recent RPA Assessment (USDA Forest Service 2023), recent exposure to drought was higher in the West than the East, and drought exposure for forests is expected to increase by 2070, with the largest increases in the Southwest. Climate change projections indicated levels of drought exposure will far exceed recent exposure for many forest type groups. By mid-century, over half of the piñon/juniper, woodland hardwoods, aspen/birch, and ponderosa pine type groups are projected to exceed the historical median exposure to severe or extreme drought.

Drought interacts with many other disturbances, both drivers and stressors, reinforcing the disturbance and most often increasing the potential threat of disturbances, such as fire, insects, and disease. Regional specialists did not identify drought as the primary stressor leading to adverse outcomes for mature and old-growth forest but instead frequently noted the interaction of a primary disturbance with climate change, particularly extended drought.

Tree Cutting

Forest disturbance from tree cutting includes a complex range of human activities that result in the felling and often removal of standing trees. For example, tree cutting can range from firewood removal for personal use or hazard tree removal, to both precommercial and commercial thinning, to commercial timber harvest, to restoration fuel treatments. The intensity and scale of tree cutting can range from removal of an individual tree for cultural uses, tree felling for wildlife habitat, to removal of many trees for wood fiber. There are various traditional and cultural purposes for tree cutting by American Indians, Alaskan Native People, and other non-Tribal communities (Conners 2002, Dockry and Hoagland 2017). The volume of wood removed, area impacted, and resulting forest condition are directly linked to the objective and methods used to remove standing trees. In instances of forest thinning, the objectives are primarily to improve forest health, while other forest management activities include removal for forest products and serving other social or cultural goals. Tree cutting on Forest Service and BLM lands is guided by Land Management Plans (LMPs) for each plan area. LMPs outline broad desired outcomes and are written through a public involvement process that influences the outcome for mature and old-growth forests. Currently, these plans generally limit stage-changing tree cutting in old-growth forest, and therefore, as illustrated in the analysis below, tree cutting seldom results in transformation of old-growth forest to an earlier developmental stage—but sometimes it does change the status of mature forests.

Tree cutting directly alters forest structure, surface fuel loading, and tree species composition along with many other characteristics. The outcome of tree cutting depends on the initial forest condition, the specific forest treatment, forest condition after tree cutting, and the forest type. Tree cutting in old forests can produce positive, neutral, or adverse outcomes, outlined below. Furthermore, outcomes from the same tree cutting activity may result in differing social, cultural, economic, and ecological outcomes (appendix 11). As an example, consider cutting of several large birch trees for cultural wood from an old forest. Some people may perceive removal of any large tree or down log as an adverse outcome. Users of certain extraordinary forest resources, such as the large birch for cultural wood, perceive the cutting differently (Nyholm 1981, Zasada 2002). Historically, Indigenous people's use of larger older trees, for example extracting planks for housing construction, would be done by removing sections of tree trunk while maintaining structural integrity. Down logs in old forest were often used for canoes and other domestic and ceremonial products (Gidmark 1995, Stryd and Feddema 1998, Turner et al. 2011).

Before presenting results of specific analyses examining current disturbances of mature and old-growth forests by tree cutting, it is helpful to consider the current extent of timber harvest relative to the past (figure 17). As outlined by Riddle (2022), commercial tree harvest on Federal lands varied over time. As Forest Reserves (later named national forests) were being established in the late 1800s

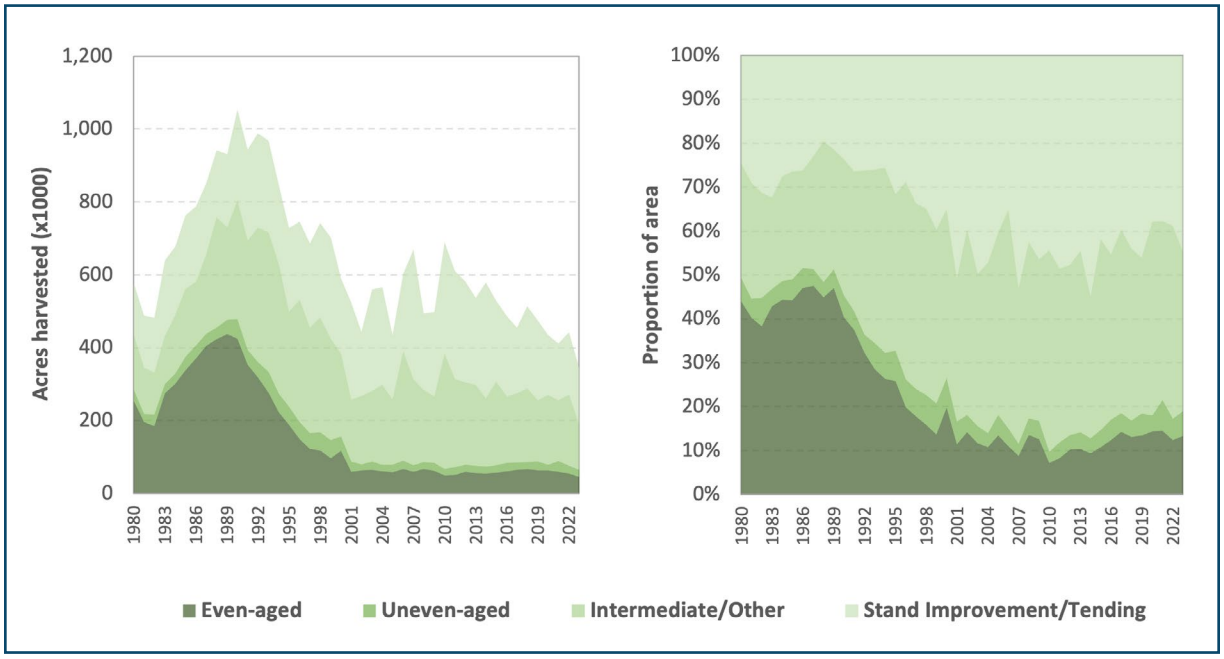


Figure 17.—Forest Service timber harvest rates since 1980 (management activity from Forest Service Activity Tracking System [FACTS] database). Even-aged harvesting removes all or most of the trees, uneven-aged leaves a mix of tree sizes, intermediate and stand improvement harvesting entails thinning of some trees for various purposes.

and early 1900s, much of the commercial timber came from private land. As this source declined, harvesting of public forest lands increased through to the 1940s, providing 2 percent of national timber supply. To meet the increasing demand for timber following WWII, the Forest Service increased harvest rates and by the 1970s, provided about 16 percent of the total U.S. harvest. Economic recessions in the early 1980s lowered demand and harvest rates (Riddle 2022). After the recession, harvest rates began increasing and peaked when the northern spotted owl (*Strix caurina occidentalis*) was listed under the Endangered Species Act in 1990.

Agency policy has changed through development and revision of LMPs, and tree cutting is no longer the most extensive threat to old-growth forest in most regions. LMPs generally include components limiting the threat of tree cutting to old-growth forest. Currently, national Forest Service annual harvest rates (not evaluated by forest development class) are about at the same level as in the 1940s and prescriptions for harvest have evolved over time. The geography of timber harvest volume on lands managed by the Forest Service reflects major production regions and milling infrastructure (Riddle 2022: Fig. 3). The Pacific Northwest Region cuts the most, followed by the Southern Region and Eastern Region. Timber harvesting on lands managed by the BLM (established in 1946) followed a similar pattern. Timber harvest began increasing in the 1950s, peaked in the 1980s, and then began decreasing in the early 1990s to current levels (Riddle 2022). Oregon and California lands provide a large share of the timber harvested from BLM lands.

Time series evaluation of national Forest Service and BLM mature and old-growth forest inventory provides evidence regarding the extent to which tree cutting removed mature and old growth during the recent past (figure 18). Remeasurement of FIA plots suggest an estimated 2.1 million acres of mature forest and 400,000 acres of old growth experienced some level of tree cutting. Hence, an estimated 2.6 percent of mature forests and 1.3 percent of old-growth forests experienced some level of tree cutting during the remeasurement period.[6] In forests experiencing tree cutting, there was an estimated net decline of 200,000 acres (0.3 percent) of mature forest and 9,000 acres (0.03 percent) of old-growth forest. In forests disturbed by cutting, impacts were low severity in 50 percent of mature and 67 percent of old-growth forests and slight increases in the extent of both occurred. This increase in extent indicates that, in many areas, tree cutting was not associated with a transition of forests to an earlier developmental stage. Impacts were severe in an estimated 6 percent of mature and 11 percent of old-growth forests where cutting occurred and were associated with net losses for both. Moderate to moderately severe cutting disturbance occurred in an estimated 44 percent of mature forests and 22 percent of old-growth forest with cutting but were associated with lower levels of net losses for both than found in severely impacted forests (figure 18). These results

6 Severity classes: low live tree loss, less than 25 percent basal area loss (including basal area gain); moderate live tree loss, 25–60 percent basal area loss; moderately severe live tree loss, 60–90 percent basal area loss; severe live tree loss greater than 90 percent basal area loss.

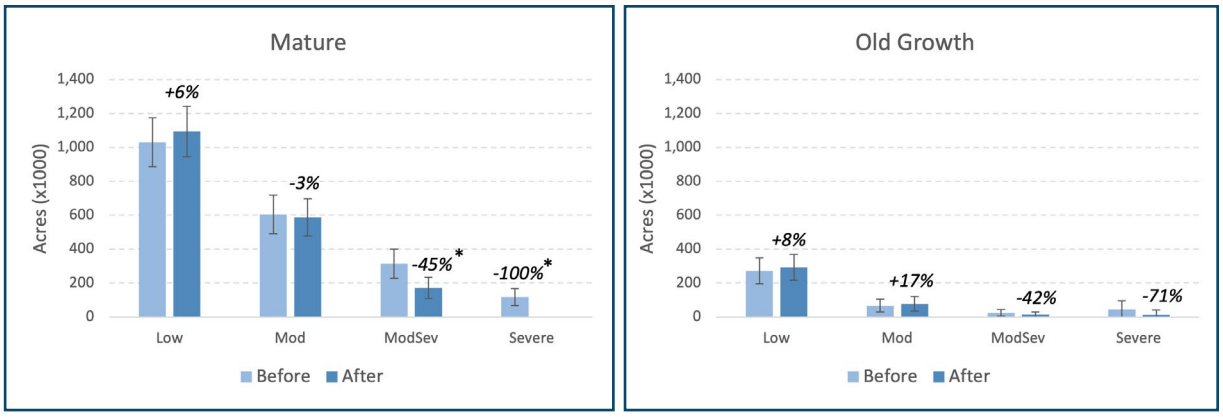


Figure 18.—Net changes (and 95-percent confidence intervals) in area of mature and old-growth forests that experienced tree cutting disturbance over an average of 9 years based on remeasured FIA plots (mostly 2000's and 2010's). Percentages represent net change by severity class and asterisks (*) indicate statistically significant net changes.

demonstrate the relationship between disturbance severity, forest condition before the disturbance, and condition following the disturbance. Threats from tree cutting occur in a subset of forest experiencing this disturbance.

The area classified as affected by cutting was sufficiently small that analysis by forest type group suggested few significant changes during the remeasurement period (at 95 percent confidence level). Nevertheless, evidence indicates the largest losses in mature forest where cutting occurred were in the Douglas-fir, lodgepole pine, fir/spruce/mountain hemlock, and ponderosa pine forest type groups (table 9). The only estimated reduction in old-growth that

Table 9.—The five forest type groups with the most change in area of mature and old-growth forest due to cutting over an average 9-year period from FIA remeasurement. Area and 95-percent confidence intervals are in thousands of acres; percents are the proportional change of the forest type.

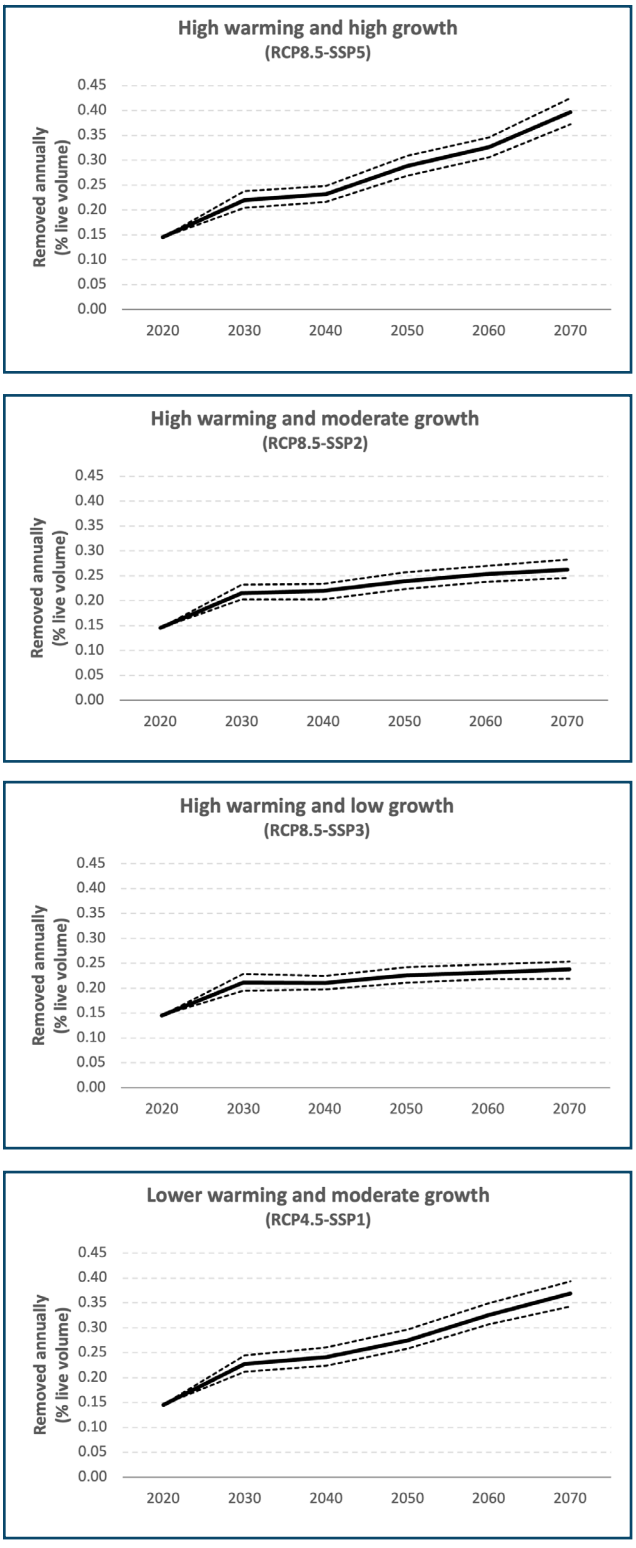
Forest Type Group	Mature Area Estimate	Mature 95% CI	Mature Percent	Old-Growth Area Estimate	Old-Growth 95% CI	Old-Growth Percent
Douglas-fir	-63.1	70.7	-0.7	23.7	38.6	0.7
Lodgepole pine	-60.7	61.6	-0.8	0.5	0.9	0
Fir/spruce/mountain hemlock	-49.7	44.6	-0.4	-2.1	10.3	0
Ponderosa pine	-45.2	73.3	-0.7	20.7	35.3	1.5
Hemlock/Sitka spruce	-4.6	11.3	-0.8	-44.3	48.7	-1.1

experienced cutting, of more than 3,000 acres during the remeasurement period was a nonsignificant loss in the hemlock/Sitka spruce group, with increases of old growth suggested for cutting that occurred in Douglas-fir and ponderosa pine forest types.

Closer examination of retrospective FIA plot data by region illustrates the substantial difference in outcomes for mature and old-growth forests (appendix 12). No region demonstrated a significant (at 95 percent confidence level) reduction in the extent of old-growth forest in forests that experienced tree cutting during the remeasurement period. This likely reflects the influence of LMP components on old-growth forest management and the significant reduction in old-growth forest harvest in Alaska over the recent decade (and to a greater extent, since the 1990s). In contrast, every Forest Service region except the Intermountain, Pacific Southwest, and Alaska Regions registered a significant decline (at 95-percent confidence level) in mature forest extent during the remeasurement period in forests experiencing at least one level of tree cutting intensity. This pattern reflects the influence of forest development (forests grew and aged during the remeasurement period), and, in some cases, stewardship approaches using tree cutting intensities that fail to change forest status to a younger development stage.

As outlined above, retrospective analysis of FIA plot data provided insights on recent influence of tree cutting on mature and old-growth forests. Our analysis also examined potential future trends. The national mature and old-growth inventory (USDA and USDI 2023) combined with 2020 RPA Assessment methods for projecting future conditions, provides insight into potential changes in the extent of mature and old-growth forest resulting from tree cutting during the next 50 years (appendix 8). Projections for tree harvest reflect relationships between forest conditions, prices, and national/global demand for wood (figure 19). Relationships are modeled separately by RPA region and ownership to incorporate regional patterns (appendix 8). Regional projections demonstrate substantial variation in projected tree cutting of mature forest but very low or no old-growth forest harvest across all regions (appendix 8). Tree cutting of mature forest increases most substantially in the Pacific Coast and South RPA regions.

National projections suggest the proportion of mature and old-growth forest removed annually by tree cutting will increase steadily for all scenarios, but at a substantially lower rate than removal by wildfires (figure 19 and figure 4). Removal by tree cutting is projected to increase by less than 0.5 percent annually with virtually all of that coming from mature forest (figure 19; see appendix 8). The future projections of harvest in mature and old-growth forests are consistent with the 2020 RPA Assessment projections for all forest land. The RPA Assessment attributes greater removal rates under the HH and LM scenarios to higher population growth and the greater use of bioenergy in these scenarios (Coulston et al. 2023). Over all forests in the contiguous United States, harvest levels decreased substantially following the Great Recession (2007–2009) but are projected to recover to prerecession levels in the HH and LM growth scenarios. These projections of harvest in mature and old-growth forests are



consistent with those overall trends. The 2020 RPA Assessment also projects forests to age on average across RPA scenarios. Between 2020 and 2070, the average age of all forests is expected to increase by 14 years in the East and 10 years in the West during the projection period. In the East, all projections suggest an increase in proportion of forest 80 years and older and a decrease in the proportion of forest less than 80 years old by 2070. However, forest management driven by timber prices associated with the LM and HH scenarios leads to less 80-year-old forest by 2070 than the other scenarios, while very young forests (0 to 9 years old) occupy similar area to 2020. In the West, the proportion of forest 100 years and older is projected to increase, with relatively large increases in the 150-plus year age class. The projections also suggest an increase in 30- to 40-year-old forest as a result of forest management and other disturbance. Like the East, projections for the 0- to 9-year age class are slightly higher under the LM and HH scenarios.

The quantitative analysis of tree cutting using FIA plot data, both retrospective and future projections (RPA), suggest tree cutting does not necessarily result in adverse outcomes—or threat—to mature and old-growth forest. Published literature and expert synthesis provide further understanding of the interaction of tree cutting with forest conditions determining whether tree cutting leads to positive, neutral, or adverse social, cultural, economic, or ecological outcomes.

Figure 19.—Observed (2020) and projected (2030–2070) future trends in annual removal rates of live tree volume in older forests (mature and old growth combined) (CONUS) based on analysis for this report. Solid lines reflect the median trend line of the median GCM (out of the five GCMs). The dashed lines represent the minimum and maximum values for the interquartile ranges (the middle 50 percent of the 100 replications) of projections across the five GCMs.

Tree cutting and associated active forest stewardship, including cultural and prescribed burning, represent well-recognized approaches to reduce the vulnerability of some mature and old-growth forest to disturbances that would otherwise remove mature and old-growth forest, transitioning them to early development stages (see citations below). Literature review and expert elicitation identified forest conditions that motivate tree cutting and associated cultural burning or prescribed fire to reduce vulnerability of both eastern and western mature and old-growth forests in frequent-fire forest ecosystems. Specialists and literature indicated that wildfire in mature and old-growth forest with uncharacteristically high tree density, low horizontal diversity, and ladder fuels are vulnerable to stand-replacement fire and therefore benefit from tree cutting to reduce lower canopy and other fuels. These are generally referred to as frequent-fire ecosystems (for example, Schmidt and McDonald 1995, Noel et al. 1998, Jain et al. 2004, Fiedler and Arno 2015, Smith and Arno 1999, Abella et al. 2007, Johnston et al. 2021, Fei and Steiner 2009, Roche et al. 2012, Beckmann et al. 2021, Devine and Harrington 2013, Reynolds et al. 2013, Hanberry et al. 2018, Kush et al. 2004, Rother et al. 2020, Palik et al. 2021). Tree cutting in frequent fire mature and old-growth forests produces a wide range of positive outcomes in addition to reducing fire severity and therefore increasing durability (see glossary). For example, stewardship that addresses uncharacteristic tree density and homogeneity can stabilize carbon in large trees and reduce mortality from endemic insects (for example, Martinson et al. 2013, Reinhardt et al. 2008).

One regionwide example stems from active forest restoration, including tree cutting, focused on longleaf pine forest ecosystems (Brockway et al. 2005). The Southern Region adopted a regionwide goal to increase representation of longleaf mature and old-growth forests while reducing vulnerability to fire and insects. Regional specialists indicate mature forests with potential to develop into old-growth longleaf pine can benefit from appropriate tree cutting and burning (Kush et al. 2004, Noel et al. 1998, Hanberry et al. 2018, Brockway et al. 2005). Effective stewardship of mature and old-growth longleaf pine provides a broad array of social, cultural, and economic benefits in addition to retaining old-growth conditions (Brockway et al. 2005).

The forest development dynamics of oak-pine, oak-hickory, and other mast producing, frequent-fire forests represent a rich example of positive social, cultural, economic, and ecological outcomes that can occur through careful tree cutting in these diverse forests that have been used by humans for millennia (for example, Nowacki and Abrams 2008, Swanston et al. 2018, Abrams 2005, Abrams et al. 2021, Fei and Steiner 2009, Hanberry and Abrams 2018, Roche et al. 2012). In the absence of disturbance, the dominant mast producing species (oak, hickory, walnut, and formerly chestnut) decline in abundance and productivity while more shade-tolerant species (for example, maple) increase in abundance, ultimately transitioning the forest from its fire-maintained hardwood dominated old-growth condition to one vulnerable to severe fire or uncharacteristic insects. In the absence of disturbance, key characteristics of the mature and old-growth mast-producing forests are lost

resulting in an adverse outcome. The adverse outcome is apparent through a cultural lens as culturally important mast foods decline, and as important wildlife decline; through a social lens as a prized open-forest structure changes; through an economic lens as recreational or subsistence hunting (mast and meat) declines, along with associated community revenue; and through an ecological lens with the loss of biodiversity as the old-growth condition fades. Regional experts and literature outline the forest characteristics before and after stewardship that together result in a positive outcome (for example, Arthur et al. 2012, Dey 2014, Oak et al. 2016, Goebel and Hix 1996, Duan et al. 2023, Hanberry et al 2018, Clark and Schweitzer 2016).

Tree cutting has been identified as a positive stewardship tool in some mature and old-growth forests that do not experience frequent, low-intensity disturbances (previous examples were all frequent-disturbance forests). Regional specialists in eastern, western, and Alaska regions indicated young, infrequent-disturbance forests with high tree density or with low horizontal heterogeneity may benefit from tree harvest to develop durable old-growth forest characteristics more rapidly (for example, Bauhus et al. 2009, for different perspective see Vizcarra et al. 2022). Similarly, southeastern specialists noted that, following heavy Fraser fir mortality from the non-native balsam woolly adelgid, limited tree cutting in mature forest may stimulate areas of spruce/fir forest to develop more complexity and more characteristic species composition and therefore old-growth characteristics more rapidly (Fassnacht et al. 2015, Busing and Garman 2002). Forests experiencing non-native insects and disease represent additional cases where infrequent-disturbance forest types may benefit from careful stewardship focused on long-term tree diversity and heterogeneity. In each of these cases, limited tree cutting would leave a mature forest condition with higher horizontal diversity and more rapid tree growth as the stand develops toward old-growth forest.

While tree cutting is identified as an effective tool to reduce vulnerability of certain forest types under specific forest conditions, tree cutting is a threat to some mature and a very limited extent of old-growth forests (see, FIA retrospective analysis, figure 18). Based on current LMPs, tree cutting more likely to occur in mature forest to a much greater extent than old-growth forest; LMP multiple use objectives and criteria identify forest conditions for commercial harvest, some of which is regeneration harvest. As described earlier, LMPs across most of the Nation restrict tree cutting in old-growth forest to conditions where tree cutting benefits the durability of the old-growth through stewardship that maintains old-growth characteristics (figure 18).

Tree harvest represents a potential threat for mature forest ecosystems most frequently in forest types that are most appropriately harvested using even-aged silviculture systems (for example, aspen, lodgepole pine, birch/poplar, Jack pine). Mature forest types typically regenerated with stand removal occur in both the eastern and western United States. When tree cutting of mature, infrequent-disturbance forests occurs, it is generally compatible with current LMPs and prescribed to meet plan desired conditions or objectives.

Tree cutting (harvest, thinning, or otherwise), is rarely recognized as a restoration prescription to reduce vulnerability for infrequent-disturbance old-growth forest ecosystems. Infrequent disturbance ecosystems in the Forest Service Southern and Eastern Regions generally face few threats that operate at sufficient spatial scale and severity to reduce large areas of mature and old-growth forest to nonmature or old-growth forest. However, as noted above, nonnative insects and diseases represent a substantial long-term threat to a range of mature and old-growth forest types. Careful stewardship specifically focused toward retaining diversity and heterogeneity may increase long-term durability in certain infrequent-disturbance forests. Tree cutting of mature infrequent-disturbance forest in the East therefore represents a potential threat, though it is compatible with current LMPs to meet multiple goals in mature forest. LMPs generally include components limiting the threat of tree cutting in old-growth forest while often allowing actions to reduce vulnerability.

Birch, aspen, and Jack pine forests in the upper Midwest and Northeast provide a useful example of the complex interaction of tree cutting and the array of associated social, cultural, economic, and ecological values. Many Indigenous people use aspen and birch for a wide range of cultural and social objects. Some of these cultural uses require exceptional trees. Local economies in some areas depend on harvest and manufacture of commercial wood products from mature aspen and birch forests. Recreation and Tribal food procurement practices (Emery et al. 2014) including fishing, hunting, hiking, and boating thrive on the character of birch and aspen stands. Tree cutting interacts with each of these uses differently. For instance, tree cutting is necessary to achieve many of the cultural benefits; often, the character of the forest is not changed by tree cutting that takes individual trees for specific cultural wood. In contrast, tree cutting for commercial products generally uses regeneration harvest in these forest types. Very different outcomes in the same forest types occurred because of different human values. Finally, the disturbance dynamics of these forests suggest that the older forest character of many Midwest and Northeastern Jack pine, birch, or aspen types will also decline in the absence of disturbance, and old-growth characteristics are unlikely to develop (Moser et al. 2015, Krasnow and Stephens 2015, Frelich and Reich 1995, Frelich 2002).

Roads

Roads can fragment and disrupt the continuity of ecosystems with numerous impacts to wildlife and ecosystem processes, most of which are adverse (Forman and Alexander 1998). They can provide conduits that increase the risk of fire starts (Miller et al. 1996, Forman et al. 2003) and the introduction and spread of invasive species (Clifford 1959, Gelbard and Belnap 2003, Watkins et al. 2003). They also can detract from characteristics perceived as important to mature and old-growth conditions, such as solitude. Conversely, roads can be viewed positively from social and economic perspectives as they provide access for recreation, fire suppression activities, and restoration work.

The following results are based on the remeasured FIA plot analysis, where changes in mature and old-growth

forest area were analyzed based on the distance from the plot to the nearest improved road maintained for travel by normal passenger vehicles. The area of mature and old-growth forest was not significantly different and did not decrease between plot measurement within a half-mile of an improved road (figure 20). Net losses were observed at distances greater than this, for mature forests, but not for old-growth forests, which showed net gains (figure 20). Gains in old growth can occur when mature forests transition into old-growth forests.

Currently, about 55 percent of mature and 67 percent of old-growth forests are greater than 0.5 mile from a maintained road. Regardless of distance, there was no record of forest disturbance in about 70 percent of mature and old-growth forests during the average 9-year remeasurement period between 2000 and 2020. The percentage of forest that was disturbed over this period varied little with distance from road, ranging between 31 to 37 percent for mature and 24 to 34 percent for old growth (figure 21). Disturbance type did tend to change with distance from road, with cutting and cutting/fire declining with increasing distance from road for both mature and old growth, and fire and insect/disease increasing with increasing distance from road for mature but not old-growth forest (figure 21).

Based on the MOGCA analysis, greater road density (assessed as miles of road per square mile in project areas containing federally owned forested land) equated to poorer ecological condition (appendix 5). Roads are an indicator in MOGCA that has impacts dispersed around the country, indicated

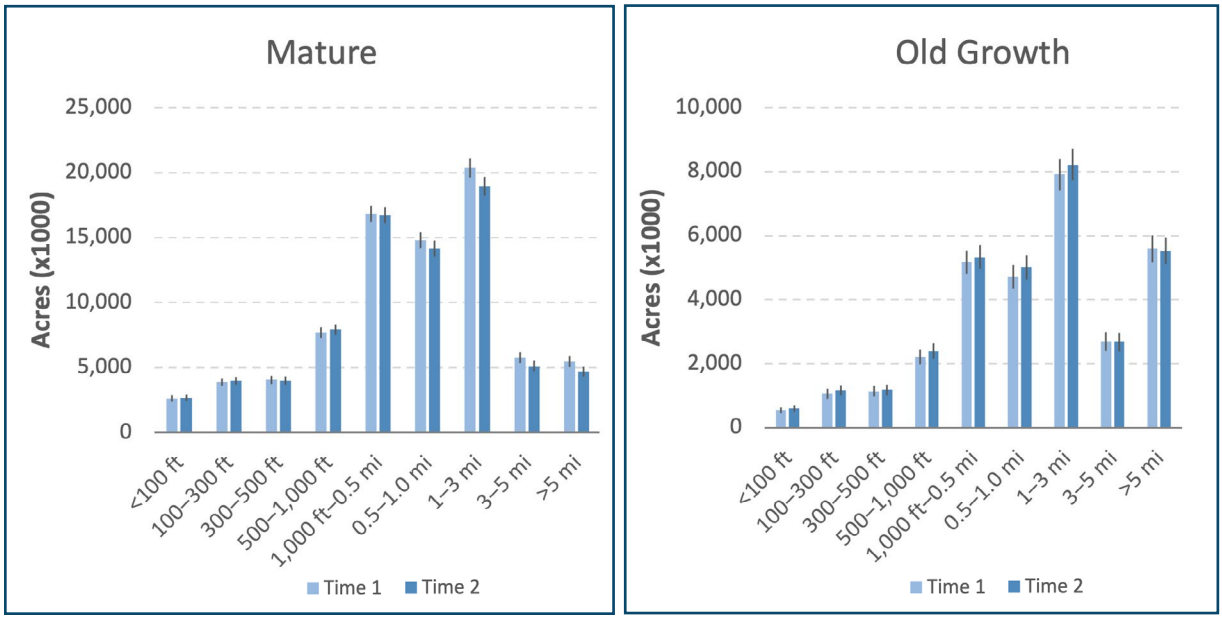


Figure 20.—Net area changes in (acres) of mature and old-growth forest by distance classes from roads. Time 1 represents first plot measurement and time 2 the second measurement. See appendix 4 for information on FIA plot measurement periods. Error bars are 95-percent confidence limits.

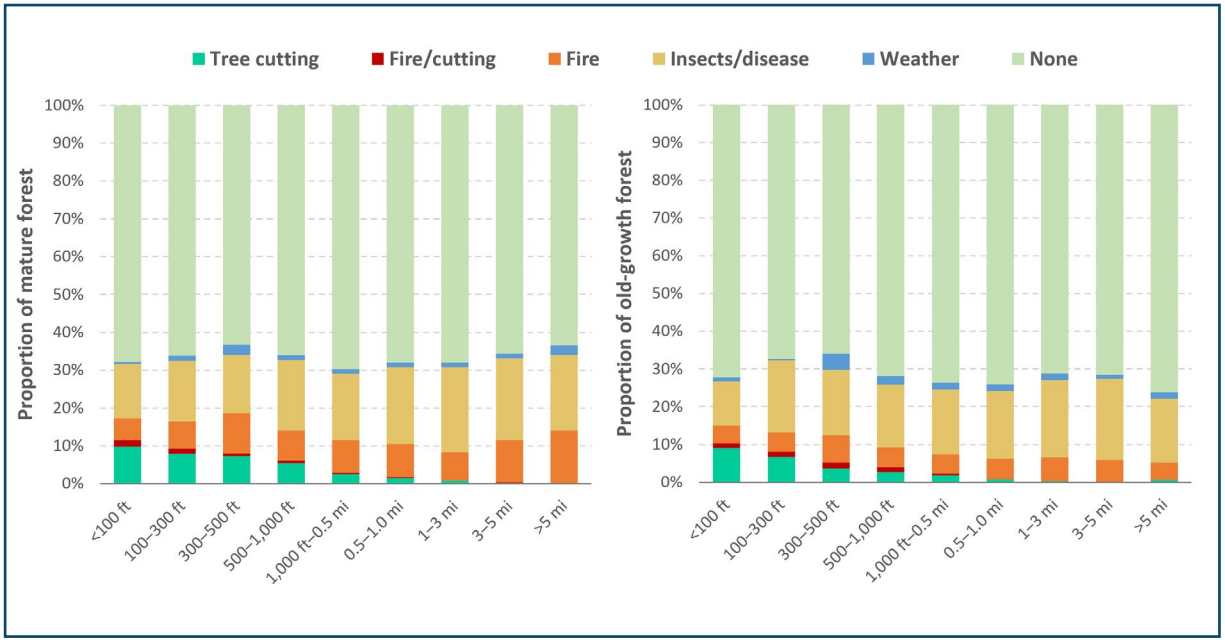


Figure 21.—Forest disturbances in mature (left) and old-growth forests (right) varied by distance to maintained roads.

by very poor ecological conditions occurring across most forest types. Different thresholds were used across road types to recognize the greater size, traffic, and ecological impacts caused by larger, paved compared to narrower, unimproved roads. Forest types with particularly high road densities include the loblolly-shortleaf pine, longleaf-slash pine, and oak-hickory forest types which are common across the eastern United States (appendix 5). Across the country, approximately 26 percent of areas with mature forest have road densities high enough to be classed as poor or very poor ecological conditions, with only 15 percent of areas with old growth meeting the same thresholds (figure 22).

Challenges associated with assessing the influence of roads on forests take multiple forms. On one hand, there is the sense that general development and human encroachment leads to direct damage and negative outcomes for mature and old-growth forests. Roads facilitate access for activities that are perceived as threats. On the other hand, roads provide positive outcomes when viewed from the angle of other conditions and through other lenses. Public access provides recreational opportunities in mature and old-growth forests which are both associated with a range of social values and can contribute to local economies. Finally, while many wildfires occur near roads, they usually account for smaller areas burned compared to areas burned by lightning-ignited wildfires in roadless areas (Narayanaraj and Wimberly 2012).

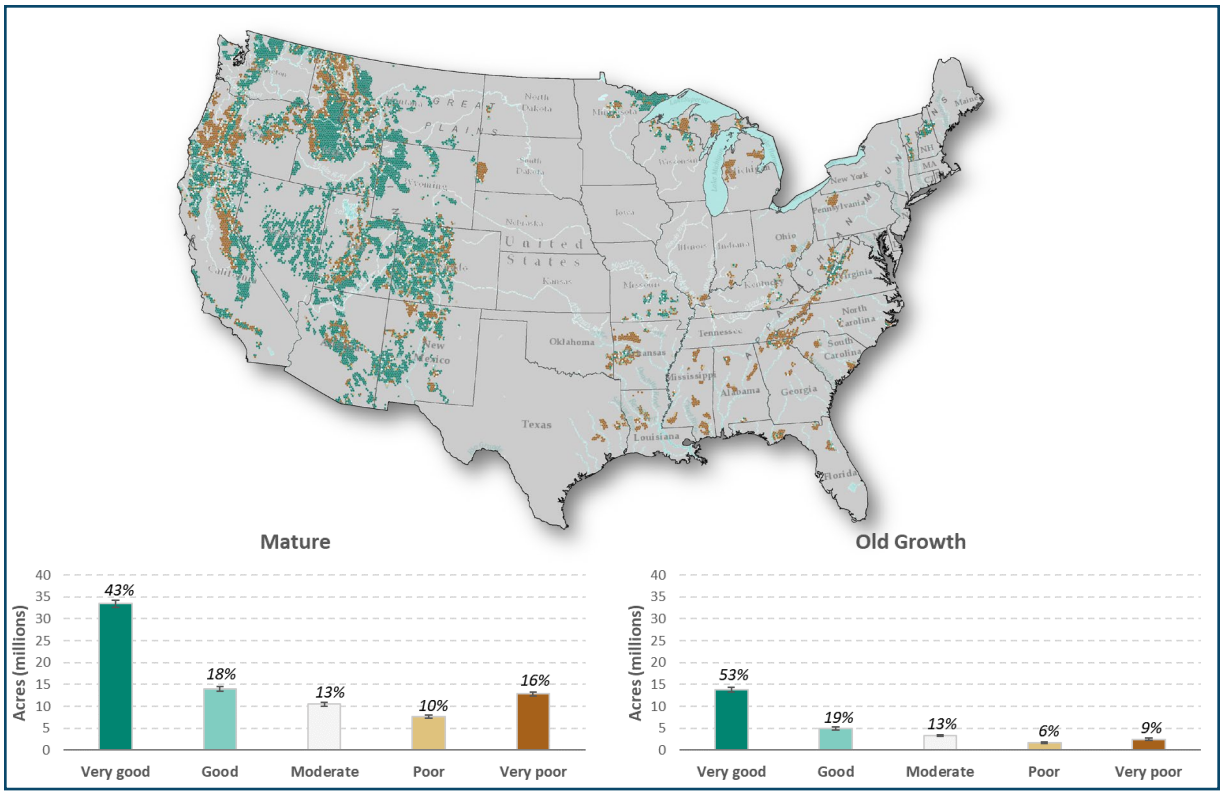


Figure 22.—Spatial patterns at the project area scale and area estimates (with 95-percent confidence intervals) of inventoried mature and old-growth forest current condition related to road density.

Mature and Old Growth Condition Assessment

A total of 22 metrics representing six condition indicators and three metrics for threat indicators were used in the Mature and Old Growth Condition Assessment (MOGCA) (appendix 5). The mature and old-growth forest condition modified by threat indicators determines the current ecological integrity (figure 23). Nearly 80 percent of all project areas (from the Fireshed Registry) were in very good or good condition. Recent tree mortality from insects and disease outbreaks and the area burned by uncharacteristically severe wildfires coincides with the areas with poorer current conditions.

More project areas (representing over 28 million acres of federally forested lands) experienced uncharacteristically severe wildfires than significant tree mortality from insects and disease. Over 60 percent of the project areas with the largest proportion of uncharacteristically severe burned areas were dominated by the California mixed conifer, Douglas-fir, ponderosa pine, and western oak forest type groups.

For current climatic conditions, MOGCA examined seasonal temperature, seasonal precipitation, and drought. Poor conditions for drought and temperature (meaning the last 5 years were significantly departed from the historical record) are concentrated in the southwestern United States in analysis units dominated by California mixed

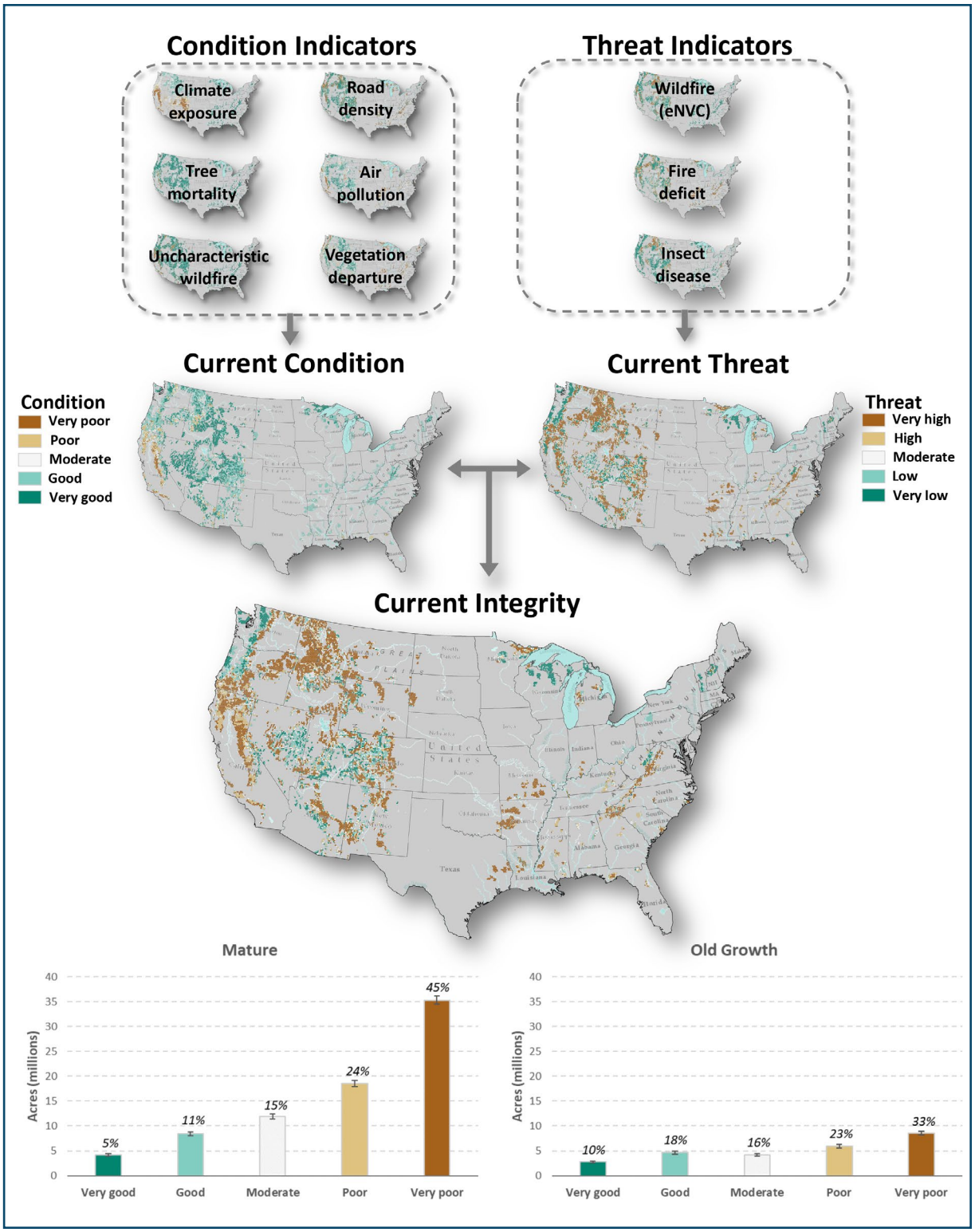


Figure 23.—Flow diagram (using project area maps) of the mature and old growth condition assessment (MOGCA). The bottom graph shows area (acres) of inventoried mature forest (left) and old-growth forest (right) in each ecological integrity class (from very good to very poor integrity). The percentages above the bars indicate the percentage of each forest type in the integrity class. This figure does not contain all of the individual metrics used (see appendix 5 for the full list).

conifer, piñon/juniper, tanoak-laurel, and western oak forest type groups. Summer temperature and precipitation have much more area in very poor conditions than the other seasons and are predominantly in the western United States. Overall, seasonal precipitation measures that indicate poorer conditions are more prevalent in the West compared to the East.

Vegetation departure was determined by relating to the deviation of the distribution of successional classes from expected distributions (LANDFIRE, Blankenship et al. 2021), and higher levels of deviation indicated poor to very poor conditions. However, with this approach, it is not discernable if that condition is due to over-representation of early, mid, or late seral stages.

Most areas of the country have air pollution conditions that are less than very good, indicating some level of nitrogen deposition above historical background rates to the point of having a likely impact on the ecosystem.

An estimated 66 percent of mature forest and 51 percent of old-growth forest are currently at high to very high exposure to the potential threats examined in MOGCA. Over half of all project areas dominated by fir/spruce/mountain hemlock, ponderosa pine, oak/hickory, loblolly/shortleaf, lodgepole, and oak/gum/cypress forest type groups are rated as having very high threats. Nearly 2,500 project areas (44 million acres) have a very high wildfire threat to late seral forests as represented by the expected net value change (eNVC), which used areas determined to be late-seral as a proxy for mature and old-growth conditions because of the need for finer spatial resolution to conduct the analysis. The eNVC indicates the overall predicted change to mature and old-growth forest if a wildfire were to occur, weighted by a burn probability (adapted from Thompson et al. 2013). The highest threats from wildfire were in western oak, fir/spruce/mountain hemlock, Douglas-fir, piñon/juniper, lodgepole pine, and California mixed conifer. High and very high insect and disease hazard conditions were found in 2,712 project areas representing nearly 24.5 million acres or 25.3 percent of federally forested lands in the contiguous United States. This is mostly in the Douglas-fir, fir/spruce/mountain hemlock, piñon/juniper, and ponderosa pine forest type groups.

The MOGCA model found the overall mature and old-growth forest integrity (as determined by the combination of current conditions and potential threats) was driven more by potential threats than by current condition (see appendix 5). Assessing both current conditions and current potential threats to mature and old-growth forests reveal that threats place more areas in poor and very poor conditions which correspond to high and very high threat. Based on this integration, the majority of mature forests (69 percent) and old growth (56 percent) have poor to very poor integrity based on high exposure to a current potential threat and/or conditions that could degrade ecosystems containing mature and old-growth forests (figure 23). But the outcome from that exposure to threats, in some cases, depends largely on the current characteristics of the forest which can be changed before a threat comes to pass.

Discussion

Mature and old-growth forests have high exposure to a variety of threats. Projects of future climate and disturbance projections show this exposure will likely increase. Currently, wildfire, exacerbated by climate change and fire exclusion, is the leading threat to mature and old-growth forests followed by insects and disease. Tree cutting (any removal of trees) is currently a relatively minor threat, despite having been a major disturbance historically. The MOGCA analysis also found that two thirds of mature forests and just over half of old-growth forests are vulnerable to current threats. Climate change has increased the level of these threats and is likely altering where, and what types of mature and old-growth forests can persist. Over the next five decades, the growth of younger and mature forests is projected to result in an increase of mature and old-growth forests despite increasing disturbance—however, at a decreasing rate over time.

Since 2000, forests affected by wildfire experienced a decrease of an estimated 2.57 million acres of mature and 712,000 acres of old-growth forests on land managed by the Forest Service and BLM (figure 24). Forests affected by insects and disease experienced a decrease of 1.86 million acres of mature forest and 182,000 acres of old-growth forest. Forests affected by tree cutting by the Forest Service and BLM experienced a decrease of 214,000 acres of mature forests and 9,000 acres of old-growth forests. Forests affected by weather and cutting/fire disturbances experienced both net loss and gains, but those losses and gains were not statistically significant. Where no forest disturbances were recorded, mature forests increased by 2.21 million acres and old-growth forests by 1.20 million acres. Combined, there has been a 2.51-million-acre net decline of mature forests, with about a tenth of this becoming old growth (a 0.28-million-acre net increase in old growth). These patterns of change vary by region and forest type (appendix 13).

Historically, tree cutting associated with timber harvesting was focused on mature and old-growth forest with merchantable sawlogs. This accounted for significant losses of mature and old-growth forests,

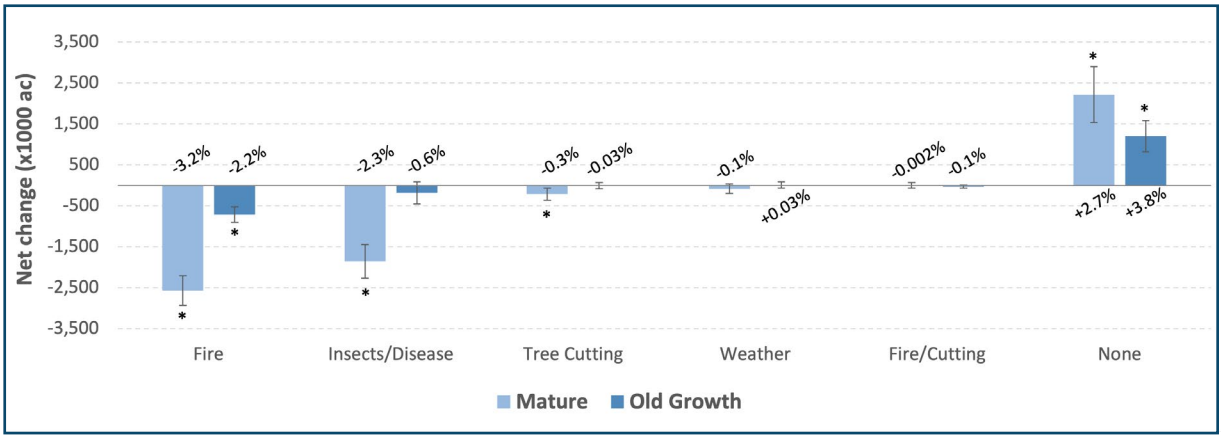


Figure 24.—National-scale results of net changes (with 95% confidence intervals) from disturbances to mature and old-growth forests recorded in remeasured FIA plots, ordered (from left to right) by largest net losses to largest net gains. Percentages are mean net changes. Asterisks (*) indicate a statistically significant net change.

setting the stage for current old growth conditions across the contiguous United States, especially in eastern forests. Beginning in the 1990s, the Forest Service and BLM started adapting to this condition (and social pressures) with decreased rates of harvesting on Federal forestlands. The type of harvesting method also changed—from one of even-aged regeneration to uneven-aged timber stand improvement and tending (figure 17). The latter methods are less adverse to the mature and old-growth condition, as reflected in the remeasured FIA analysis results (figure 25).

The FIA remeasurement analysis of forest disturbances suggests that disturbances may not always result in adverse outcomes (threats) to mature and old-growth forest. Disturbances of lower severities did not result in net area losses, in many cases. Of all disturbances, fire proportionally had higher severities, followed by fire/cutting, tree cutting, insects and disease, and weather. Insects and disease, while mostly of lower severities, ranked as the second leading disturbance experiencing loss of mature and old-growth forests. This is likely owing to the slow accumulation of annual loss over the remeasurement period (figure 25).

Spatial analyses of historical, current, and future climatic conditions and exposure showed noticeable changes between historical and current conditions consistent with the findings in regional climate change vulnerability assessments, national reports, and syntheses (USDA Forest Service 2023, USGCRP 2023) (appendix 14). The story varies across the country but has

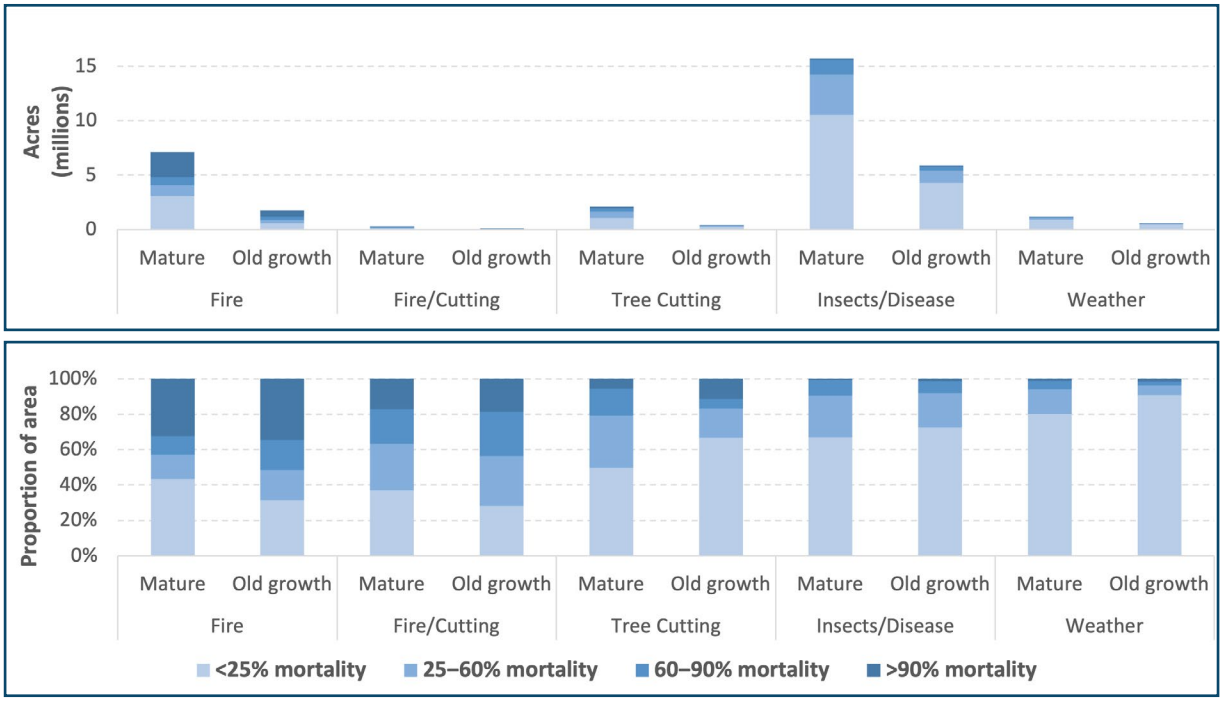


Figure 25.—Forest disturbances from remeasured FIA plots at the national scale. Disturbances are ordered (from left to right) by proportion of total area disturbed by moderately severe (ModSev) to severe disturbances (>60 percent live tree basal area mortality).

consistent threads. In the northeastern portion of the Eastern Region, mean annual temperature has increased by 2.4 °Fahrenheit, a slight increase in precipitation, but a substantial increase in extreme precipitation events over the historical record from 1901 through 2011. Global circulation model data projected an increased temperature of 3 to 8 °Fahrenheit and fall and winter precipitation by the end of this century. Effects of projected climatic condition changes on future tree distributions is expected to range from adverse to beneficial. Montane spruce/fir, low-elevation spruce/fir, and lowland mixed conifer forests were determined to be the most vulnerable and hardwoods and pitch pine/scrub oak forests were less vulnerable (Janowiak et al. 2018).

In the Pacific Northwest Region, southwestern Washington State GCMs project warming will continue throughout the 21st century (Hudec et al. 2019). Compared to observed historical temperature (1950–1979), average warming is projected to increase by 7.7 to 11.5 °Fahrenheit (RCP8.5). Seasonally, the largest increase is projected for the summer (10.3 to 12.2 °Fahrenheit). Mean summer precipitation is projected to decrease from 162 mm historically to 87 to 21 mm by the end of the century, while extreme precipitation events are likely to increase. Higher air temperature, through its influence on soil moisture, is expected to cause gradual changes in the abundance and distribution of vegetation species, with drought-tolerant species being more competitive. Increased occurrence of wildfire, insect outbreaks, and disease will drive forest landscape change. More frequent fires would favor fire-adapted tree species, such as lodgepole pine, but adversely affect fire-sensitive species, such as western hemlock (Hudec et al. 2019). In southwestern Oregon, average warming is projected to increase 4.3 to 10.1 °Fahrenheit by the end of the 21st century (RCP8.5). Climatic water deficit will double, suggesting substantial increases in drought stress for plants. Climate and fire refugia will facilitate tree species persistence with climate change (Hoyer 2022). In the North Cascades, the current warming trend is expected to continue, with average warming increasing by 3.8 °Fahrenheit by the 2040s and 6.8 °Fahrenheit by the 2080s; precipitation may vary. Higher temperatures will increase stress and lower the growth and productivity of lower elevation forests but increase it for high-elevation forests. Forest distributions are expected to change over the long term, and increased disturbance (wildfire, insects, and invasive species) will cause rapid changes in ecosystem structure and function across broad landscapes (Raymond et al. 2014). In the Blue Mountains of Oregon, GCMs project that the current warming trend will continue throughout the 21st century, with average warming increasing by 5.8 to 11.3 °Fahrenheit by 2100, depending on greenhouse gas emissions. Frequency of extreme climate events (drought, low snowpack) and associated effects on ecological disturbance (streamflow, wildfire, insect outbreaks) is expected to increase (Halofsky and Peterson 2017).

In the northern Rocky Mountain Region, average warming is projected to be about 4 to 5 °Fahrenheit higher than historical temperatures by 2050, and climatic extremes will probably be more common (Halofsky et al. 2018a). And in the Intermountain Region, higher temperatures and drought are expected to increase the frequency and magnitude of wildfires, insect outbreaks (both native

and nonnative), and reduce the area of mature forest (Halofsky et al. 2018b). Increased temperatures are expected to cause a gradual change in the geography of forest types with extreme heat events likely to become more common and exposure projected to be more pronounced at lower elevations (Rice et al. 2018).

Alaska has warmed twice as rapidly as the global average during the first decade of this century with statewide average temperatures for 2014–2016 notably warmer as compared to the last few decades (Markon et al. 2018). The State is expected to become even warmer by the middle of this century, with earlier springs, later falls, longer growing seasons, and shorter/less-severe winters (Hayward et al. 2017). Most climate models predict that high latitudes will experience a much larger rise in temperature than the rest of the globe through the remainder of the 21st century. Reduced snowpack is contributing to rangewide mortality increases for yellow-cedar (Hennon et al. 2012).

In the Southern Region, sea level rise, hurricanes, extreme heat, and decreased water availability are the major stressors. The number of days with temperatures above 95 °Fahrenheit is expected to increase by as much as 50 days per year. Summer precipitation is expected to fluctuate, with both increases and decreases in precipitation varying across the region. Extreme weather events increased by 22 percent during the 20th century and hurricane-related damage has increased markedly this century (McNulty et al. 2015).

Forests in the contiguous United States are experiencing increasing annual amounts of forest disturbance, in particular slow/chronic disturbances associated with climate-related stress as well as secondary stressors such as insect and disease that occur over a prolonged period of time (years) (Cohen et al. 2016). Landscape Change Monitoring System (LCMS) data[7] of slow disturbances illustrate this phenomenon when summarized by regional cumulative firesheds (figure 26). As noted by Cohen et al. (2016), this forest decline appears to be associated with diminishing forest health (or increasing stress) leading to tree canopy cover loss and increases in tree mortality above historical background levels.

Temporal and spatial patterns in slow/chronic forest disturbance coincide with recent insect and disease maps and are consistent with findings in several climate change vulnerability assessments (appendix 14). Chronic disturbance began increasing above background levels earliest (early- to mid-1990s) in the Rocky Mountain, Southwest, and Intermountain Regions which occur in the dry ecosystem domain.[8] This coincided with a mountain pine beetle outbreak on three national forests in the Rocky Mountain Region that began in 1996, and by 2010 it had spread to about 4 million acres (USDA Forest Service 2011) and continues to increase. Surrounding this area are the Northern, Pacific Southwest, and Pacific Northwest Regions, where chronic disturbance began increasing above background levels this century, beginning in the dry domain (Northern Region) and later in the humid ecosystem domain (Pacific

7 https://data.fs.usda.gov/geodata/rastergateway/LCMS/

8 https://www.fs.usda.gov/land/ecosysmgmt/colorimagemap/ecoreg1_domains.html

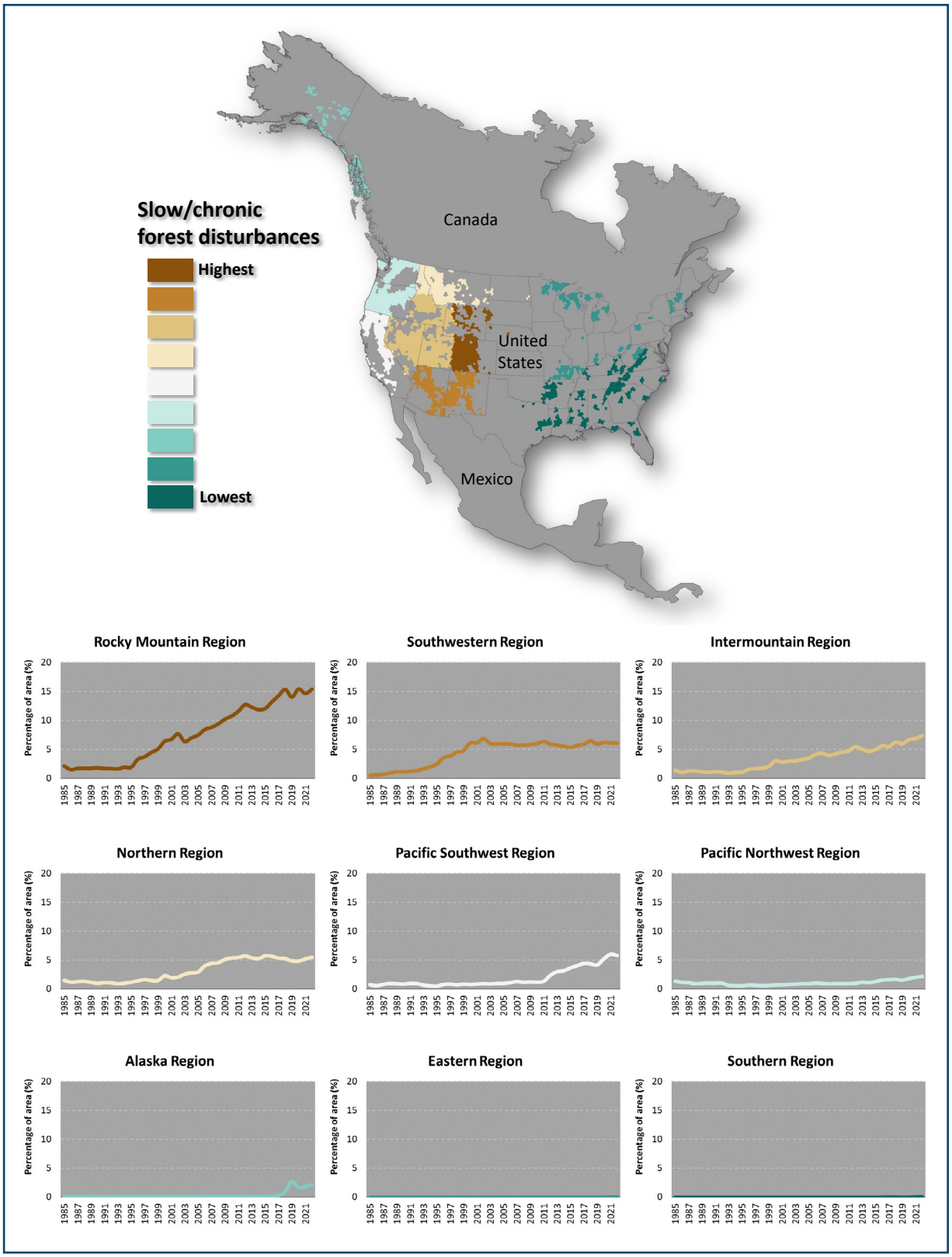


Figure 26.—Long-term trends in slow/chronic forest disturbance as loss of live tree canopy cover and tree mortality above historical background levels. Data from the Landscape Change Monitoring System Program Data Explorer (https://apps.fs.usda.gov/lcms-viewer/).

Southwest and Northwest Regions). Western pine beetle outbreaks contributed to mortality of 129 million trees in California from 2010 to 2017 (Vose et al. 2018). Departure from background levels only recently began around 2015 in Alaska and have not, as of yet, increased in the humid Eastern Region, which is largely expected to undergo gradual change, punctuated by rapid changes (Vose et al. 2018). The humid Southern Region experienced no detectable slow/chronic changes (lowest of all regions) but has a high amount of annual prescribed fire that may, in some part, account for this.

Despite the changes that have already occurred, current mature and old-growth forest conditions are mostly good. However, the integrity of mature and old-growth forests is mostly low because of the potential threats, which are high to very high for over half of the inventoried mature and old-growth forests. Although drivers of slow/chronic and fast (such as tree cutting and wildfires) forest loss are expected to increase, projections on Forest Service and BLM forestlands over the next 50 years show increases in mature and old-growth forests areas, based on modelling conducted under the RPA Assessment scenarios (figure 27). However, the estimated annual rate of change decreases at every time step (decade) for all scenarios and becomes negative for two scenarios (HH and LM) by 2070. The projected increase in mature and old-growth forest area is mostly attributable to projected increases in old-growth forest over time (appendix 8). Younger forest decreases for all scenarios. Younger, mature, and old-growth trends from these projections were consistent with the overall forest succession and aging trends projected for all forests in the contiguous United States in the 2020 RPA Assessment (Coulston et al. 2023). Regional differences are shown in appendix 8.

Climate change is already underway, resulting in higher temperatures, more frequent drought, and increased forest disturbances. It is expected that it will decrease the ability of many forest ecosystems to provide important ecosystem services to society (Vose et al. 2021).

The results of this analysis and the input received from public and other interested parties corroborate the potential threats to mature and old-growth forests identified in E.O. 14072 (with some nuances) and are consistent with existing science and climate change vulnerability assessments (appendix 14). As described in this analysis, outcomes of exposure to threats will depend on forest conditions that mitigate some threats, reducing vulnerability. The results also reflect values placed on mature and old-growth forests that are complex, reflect the interests of diverse cultures, economic constituencies, geographic context, and oftentimes represent contested terrain. Conflict is exacerbated by significant stressors in the form of climate change and the political environment, each of which carries instability, uncertainty, and extremes. For example, the political controversy over climate change causality plays strongly in the discourse regarding threats to mature and old-growth forests. Such factors are important considerations for evaluating this analysis.

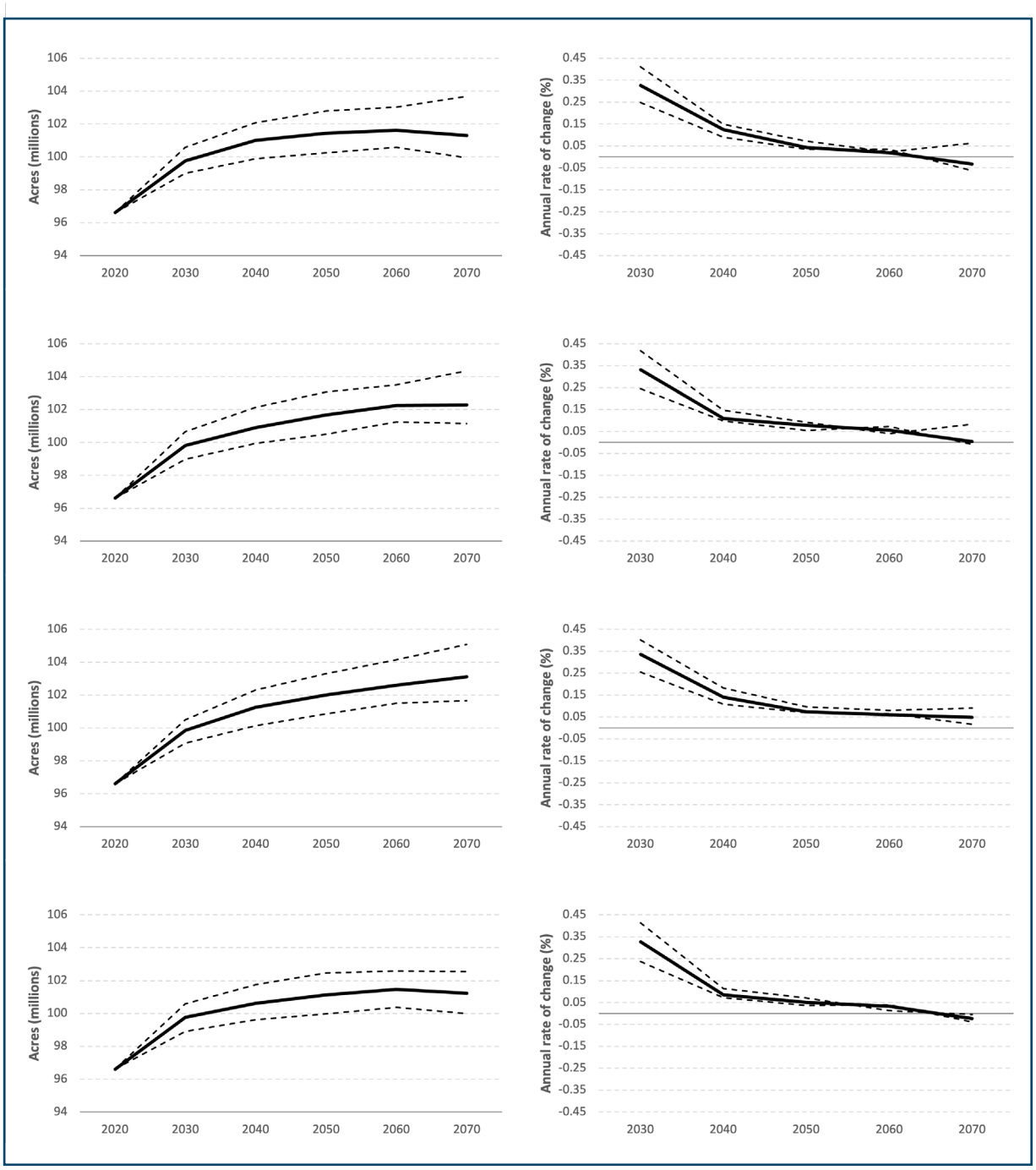


Figure 27.—Observed (2020) and projected (2030–2070) trends in mature and old-growth forests (mature and old growth combined) (CONUS). Solid lines reflect the median trend line of the median GCM (out of the five GCMs). The dashed lines represent the minimum and maximum values for the interquartile ranges (the middle 50 percent of the 100 replications) of projections across the five GCMs.

Management Considerations and Challenges

Changes in mature and old-growth forests managed by the Forest Service and BLM were examined by land use designations. Plots in designated and candidate Wilderness Areas, Inventoried Roadless Areas, and National Monuments were identified and contrasted with all other administrative categories. The patterns of change were so similar between wilderness and roadless areas, and the area in national monuments so small, that these areas were combined and are referred to as "reserved." There was a 10-percent decline in mature forest in reserved areas over an average 9-year period, primarily due to impacts from fire and insects and disease (figure 28). Old-growth forests in reserved areas declined by a (nonstatistically significant) 0.4 percent, with increases in undisturbed forests almost balancing decreases in areas impacted by fire and insects and disease. Similarly, mature forest outside of reserved areas declined by a nonstatistically significant 0.4 percent, with increases in undisturbed forests almost balancing decreases in areas impacted by tree cutting, fire, and insects and disease. However, old growth outside of reserved areas increased by 7.8 percent, with minor impacts from disturbances outweighed by the increases. These results suggest that strictly reserving mature and old-growth forests may not always ensure that they are protected from future losses.

Understanding the distribution of mature and old-growth forests within national and regional priority landscapes is an important consideration. In response to the Bipartisan Infrastructure Law (January 2022)[9] the Forest Service launched a robust, 10-year strategy-

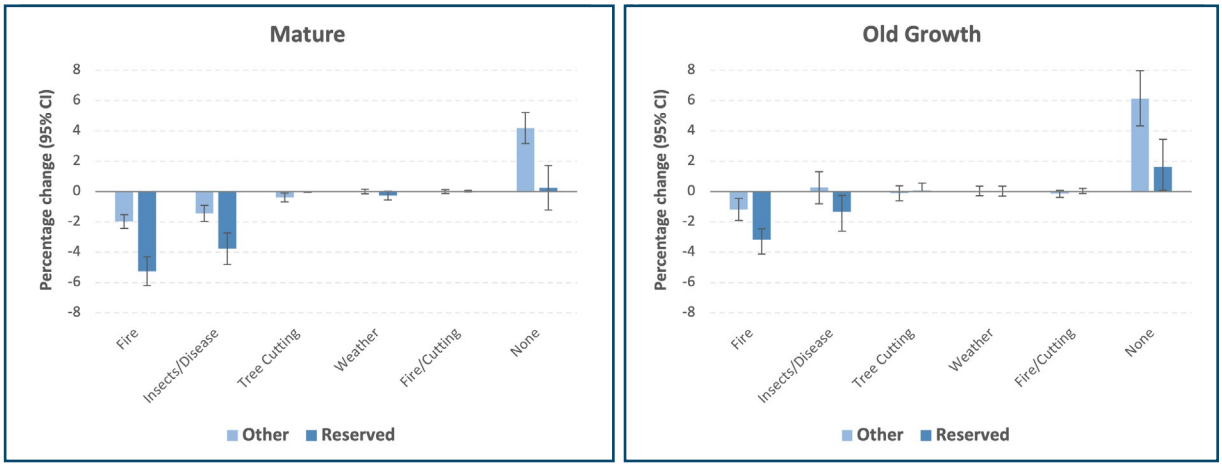


Figure 28.—Net percentage area changes in mature and old-growth forest (and 95-percent confidence intervals) since the first measurement (time 1) over an average of 9 years within and outside of reserved areas, from remeasured FIA plots.

9 https://www.whitehouse.gov/build/guidebook/

to address the wildfire crisis in places where wildfire poses the most immediate threats to communities. The strategy, Confronting the Wildfire Crisis: A Strategy for Protecting Communities and Improving Resilience in America's Forests, combines a historic investment of congressional funding with years of scientific research and planning into a national effort to dramatically increase the scale and pace of active forest stewardship over the next decade. With this strategy, the agency will work with States, Tribes, and partners to address wildfire risks to critical infrastructure, protect communities, and make forests more resilient.

In April 2022, in coordination with partners, the Forest Service announced that 10 of the highest priority western landscapes would receive an initial investment of $131 million in FY 2022 under the Bipartisan Infrastructure Law. The selected landscapes contain 68 high-risk firesheds and about 13 million acres to apply the funds for active forest treatment projects. The selected landscapes overlap with identified lands managed by the Forest Service in the West that require some level of immediate treatment. In early 2023, the Forest Service added 11 additional landscapes for a total of 21 identified landscapes. Estimates show that 16 percent of all estimated mature forest and 13 percent of all estimated old-growth forests on lands managed by the Forest Service are found within Wildfire Crisis Strategy Landscapes (table 10).

A Notice of Intent (NOI) to amend the Northwest Forest Plan (NWFP) was published on December 18, 2023.[10] The NOI acknowledges substantial new and relevant information including E.O. 14072. The Forest Service is proposing, "to amend NWFP direction, addressing changed conditions and new information, to improve resistance and resilience to fire where needed across the NWFP landscape, support adaptation to and mitigation of climate change in the NWFP landscape, address management needs of mature and old-growth forests with related ecosystem

Table 10.—Estimates of mature and old growth forest contained within Wildfire Crisis Strategy priority firesheds.

Agency & Land Use Allocation	Younger Forest		Mature		Old Growth	
	acres	*SE%*	*acres*	*SE%*	*acres*	*SE%*
Forest Service Total	**51,452,872**	**1**	**68,136,957**	**1**	**24,738,364**	**1**
WCS Landscapes	8,732,550	2	11,210,296	2	3,261,365	4
Non-WCS Landscapes	42,720,322	1	56,926,662	1	21,476,999	1
BLM Total	**13,218,861**	**2**	**12,619,046**	**2**	**8,331,991**	**3**
WCS Landscapes	378,360	12	404,462	12	79,862	27
Non-WCS Landscapes	12,840,500	2	12,214,584	2	8,252,129	3

10 https://www.federalregister.gov/documents/2023/12/18/2023-27742/region-5-and-region-6-california-oregon-and-washington-forest-plan-amendment-for-planning-and

habitat improvement, and contribute predictable supplies of timber and nontimber products to support economic sustainability in communities affected by forest management in the NWFP landscape, including addressing environmental justice concerns and ensuring Tribal inclusion in developing and implementing plan direction in the NWFP." The proposed amendment includes actions that support the Wildfire Crisis Strategy and strengthen relationships with Tribal Nations and Indigenous peoples. Both efforts are consistent with E.O. 14072 (Section 1), which describes developing policy that consults with State, local, Tribal, and territorial governments, as well as the private sector, nonprofit organizations, labor unions, and the scientific community, to pursue science-based, sustainable forest and land management to conserve America's mature and old-growth forests on Federal lands.

In addition to the considerations above, managing the mature and old-growth forest threats identified in this analysis will be challenged by existing mill infrastructure and timber processors. The geography of the current milling infrastructure is a legacy of historical logging patterns and proximity to transportation systems. The density and size (processing capacity) of mills also corresponds to geographies where landownership is diverse, with privately managed timberlands and industrial forest ground nearby. Changes in raw material supply and fluctuations in timber availability from various land ownership have also impacted the milling infrastructure across the landscape. Mills vary a great deal by size, overall log volume they can process, and the size of material they can handle—therefore the potential interaction with surrounding forests can also vary widely. The majority (81 percent) of mature and old-growth forest are in firesheds with very low or low timber processing capacity, while 8 percent are in firesheds with very high or high capacity. Mill capacity was highest in the Pacific Northwest and Southeast Regions of the country (figure 29). This situation, along with evidence presented in the current analysis, demonstrates that most mature and old-growth forest is under a low level of threat from loss due to commercial harvest. However, lack of mills presents barriers for conducting management activities aimed at reducing risk from fire, insects, and diseases in an economically viable way. About half of inventoried mature and old-growth forests occur in firesheds where wood processing capacity is low, but current threats are high (figure 29), suggesting these areas may struggle to practice active management to reduce forest vulnerability.

In addition to milling capacity, a timber harvesting workforce is needed, and may not exist in places where mill infrastructure is limited or absent. The firesheds designated as very low milling capacity are dominated by piñon/juniper forests (such as in the Intermountain and Southwest Regions). Piñon/juniper forests are not as economically viable from a classic timber production standpoint but are also not reliant on mill infrastructure for management activities intended to promote resilience. Further, much of the woody material that needs to be removed to reduce risk from the discussed threats is not logs and is more challenging to remove when infrastructure does not exist to turn that material into forest products. The Public Lands Act of 2009 included an innovative policy that established

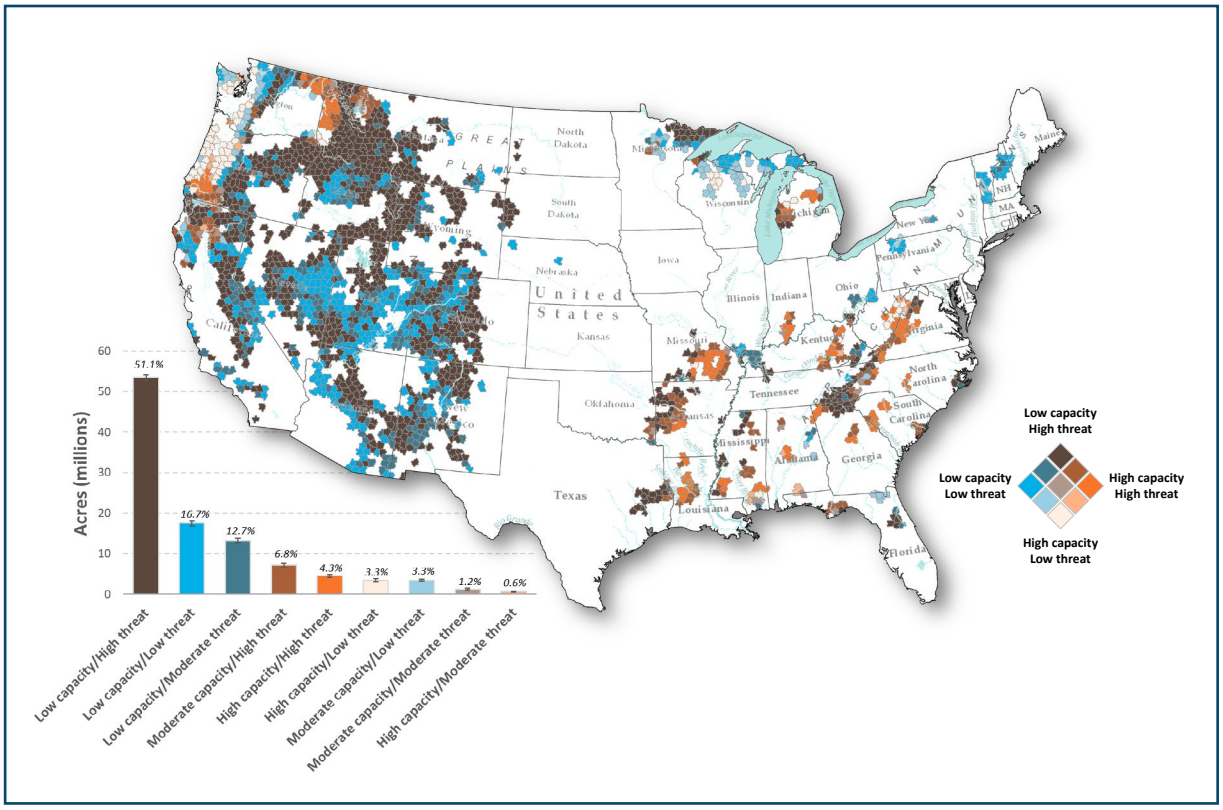


Figure 29.—Mill processing capacity overlayed with potential threats from fire deficit, fire threat, and insect/disease at the fireshed level for firesheds containing mature and old-growth forest managed by the Forest Service and BLM. Mill capacity was a sum of total volume within the fireshed, plus a 50km buffer. Very low= 0–6, 250 MCF (1,000 cubic feet); low= 6,251–18,000 MCF; moderate= 18,001–33,750 MCF; high= 33,751–61,750 MCF; very high= 61,751–111,625 MCF.

Collaborative Forest Landscape Restoration Programs (CFLRP[11]) that encouraged investment in new types of wood-processing infrastructure. This includes wood-processing mills that are adapting to nontraditional sources (for example, small diameter wood) and producing non-traditional products such as wood pellets.

Another consideration and challenge are the juxtaposition of human infrastructure, mature and old-growth forests, and potential forest threats. The wildland-urban interface is where housing meets or intermingles with wildland vegetation, such as forests (Radeloff et al. 2018). Following a 2001 definition in the Federal Register, scientists have mapped the wildland-urban interface consistently each decade from 1990 to 2020, combining census data on housing and remotely sensed land cover data for the conterminous United States (Radeloff et al. 2022). From 1990 to 2020, the interface footprint expanded by 31 percent (Radeloff et al. 2018). The relationship between fire deficit and the wildland-urban interface demonstrates both challenges and opportunities. The close proximity of humans and housing to the wildland can limit opportunities for

11 https://www.fs.usda.gov/restoration/CFLRP/

prescribed fire use and increase the risk of wildfire ignitions (Kobziar et al. 2015), which in turn increases the risk of higher severity fires. Alternatively increased investment through, for example, Community Wildfire Defense Grants, could provide the opportunity for more targeted maintenance and restoration efforts with positive desired effects to mature and old-growth forests. From 1990 to 2020, although firesheds containing Federal mature and old-growth forests only had a low percentage of growth in areas classified as wildland-urban (2 percent, compared to 31 percent growth in the wildland-urban interface area nationally), housing units within those same firesheds increased by a much greater proportion (43 percent, compared to 37 percent growth in housing units nationally). This trend suggests significant growth in housing near mature and old-growth forests (figure 30).

Because the wildland-urban interface creates challenges for implementing fuels treatments using planned ignitions, we further examined where high threat from fire deficit condition and moderate- to high-growth in housing units coincide near old-growth forests on federally managed land. Firesheds with high population growth and high threat from fire deficits are found across the country, with concentrations in the intermountain west and southeast areas. The West contains a diversity of combined conditions while less variation is seen in the East. These conditions are present in 25 percent of mature forest acres and 17 percent of old-growth forest acres.

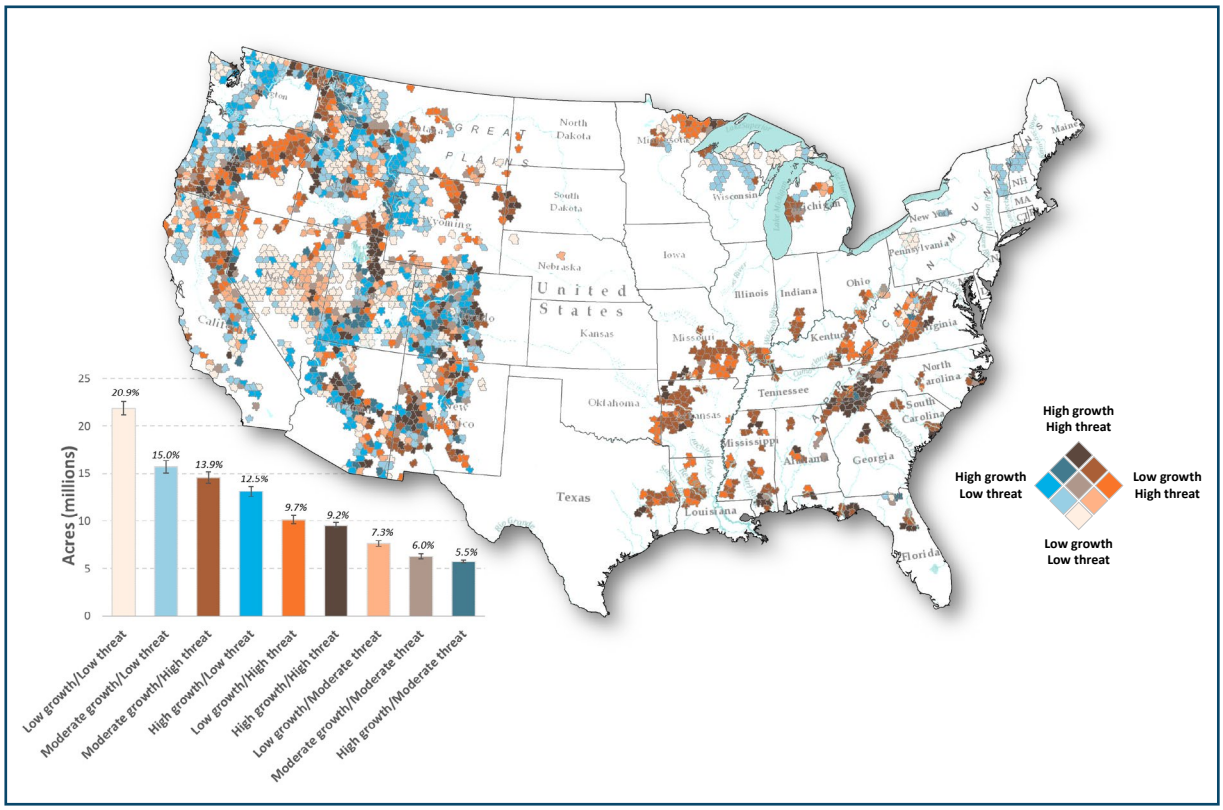


Figure 30.—Overlay analysis of housing unit change from 1990–2020 summarized to firesheds and fire deficit condition for Federal mature and old-growth forest firesheds.

Conclusion

This report is a rapid analysis on the influence of various disturbances and the conditions under which those drivers and stressors become potential threats to mature and old-growth forests. Some of the threats analyzed were mentioned in E.O. 14072, and some not. The analysis validated the conception that uncharacteristically severe fires are indeed threats. It also showed that climate change poses threats and has already increased the exposure of inventoried mature and old-growth forests to some of these threats. Climate change is projected to continue increasing threat exposure into the future. This trend begins to decrease under some socio-economic/climate change scenarios by mid-century, and climate change projections beyond this point—and to the end of this century—paint a concerning picture.

While timber harvesting is recognized as the historical cause for loss of much of the Nation's mature and old-growth forests, current data show that the leading cause for losses on forestlands managed by the Forest Service and BLM is from wildfires. Second to wildfire is the loss of mature and old-growth forests from insects and disease. Nationally, recent losses from tree cutting are third, accounting for less than one percent of net losses (mostly in mature forest) this century.

As recognized in E.O. 14072 (Section 1), the world's mature and old-growth forests are quickly disappearing and only a small fraction of what existed historically remains. Given the recognized importance of this natural resource to ecosystem integrity that supports economic, social, and cultural values, it is important to understand potential threats. This latest effort to understand the threats builds on previous evaluations. The fate of the Nation's mature and old-growth forests has been of concern for over a century (Greeley 1925; figures 31 and 32, box 3). The future of mature and old-growth forests that remained on federally managed lands has been of concern since the 1980s (USDA Forest Service 1989). Conservation of older forests has largely been a Federal land management issue because, by some estimates, Federal lands are where much of it remains or is concentrated (Thomas et al. 1988, Gordon et al. 2008, Barnett et al. 2023, DellaSala et al. 2022). As stated by Thomas et al. (1988), how much is needed depends on *"For what purpose is maintenance of old growth being considered* and *… must be predicated on the relatively small amount of unevenly distributed remaining old growth."* Thomas, who later became the 13th Chief of the Forest Service, concluded that *"…the best probability of success is to preserve all remaining old growth and, if possible, produce more."* This assumed that all the remaining old growth of the time was the "right type" of old growth and part of a resilient ecosystem. However, the history and the effects of over a century of fire exclusion on fire-prone and fire-adapted forest types are now better understood. The definitions used in the inventory were based on FIA plot data that reflect current conditions and past management. In forests where fire was historically less frequent, they likely represent the forest conditions appropriate for the environment and disturbance regime. But, in areas where fire was historically frequent and has been suppressed, these data do not reflect ecologically appropriate conditions—they reflect altered conditions (Spies et al. 2018).

The presence of older (often larger) trees is an important characteristic of old growth, but if the area has experienced significant fire exclusion, those stands of mature and old-growth forests may not be in a condition conducive to their longevity. Closed canopy, structurally complex old growth normally occurs in moister/cooler conditions that can support this dense growth. The trees in these areas tend to be fire-sensitive or least resistant to surviving fire. Where the environment is warmer and drier, the forests are normally less dense and more open-canopied, consisting of tree species that have adapted to the frequent occurrence of fires. These are general observations, but there is a growing body of evidence that some of the current mature and old-growth forest inventory includes "fire-excluded" mature and old-growth forest, forests that have expanded from fire refugium (see figure 6, figure 8, table 3, table 4, table 5, and table 6), and forest that have developed stand structure and species compositions uncharacteristic of the historical fire regime.

This initial analysis suggests the Forest Service and BLM still have an opportunity to manage mature and old-growth forests on their respective lands to be adaptive and resilient to future threats. Opportunity comes from a combination of the fact that Federal lands contain much of the mature and old-growth forests and the area of mature and old-growth forests is expected to increase (at least in the next few decades). However, the threats are also expected to increase in the future with climate change. Moving forward, projections of increasing mature and old-growth forests are tempered by the reality that American forests are entering uncharted territory with climate change. As our understanding of the implications of climate change evolves, so will understanding the places and methods to best steward and conserve our Nation's older forests for the longest time and for the greatest good.

Old-growth ponderosa pine forest stand on the Fremont-Winema National Forest, Oregon. USDA Forest Service photo.

When Europeans began colonizing the conterminous United States, they encountered immense and diverse forested landscapes. Tree species composition, stand structure, and landscape patterns were shaped by and evolved with the climate and underlying disturbance regimes, especially fire. Many of these forests were also shaped by thousands of years of human use and fires set by the Indigenous populations that lived in or near them. Three centuries later, concerns were raised about the future of these forests as they related to the Nation's timber supply. This compelled the third Chief of the Forest Service (William Greeley) to publish a paper about the relationship between geography and the timber supply. In it, he wrote the following:

"The course of these nations in satisfying their requirements for forest-grown materials has usually run through three different stages. At first, they have cut freely from their own virgin forests as long as the supply lasted. Then they have cast about for what they might barter from their neighbors. And finally, they have settled down to the systematic growing of wood on all the land that could be spared for the purpose." (Greeley 1925)

He illustrated this change in a series of hand-drawn maps (transcribed to firesheds in the following plates) and concluded that:

"The United States is still in the first of these three stages. By far the greater part of the wood we use is still obtained from our own virgin forests. But the end of this supply is plainly in sight."

Concern in the 1920s was focused on the Nation's timber supply. Today there is a much broader array of social, economic, and cultural values, as outlined in Executive Order 14072. The focus now extends to the myriad of ecosystem services, especially those uniquely provided by older forests, including carbon sequestration and storage, climate change mitigation, and biodiversity.

The concern is heightened because of increasing signs and symptoms of a changing climate. Wildfires are increasing in frequency and extent. Droughts are lasting longer and are more intense, stressing the health of forests and making them more susceptible to adverse impacts from insects, diseases, and other stressors. And record-breaking heatwaves are more commonplace, with records broken annually. How do we conserve and restore mature and old-growth forests that remain into the future?

Box 3.—Historical context of mature and old-growth forest management.

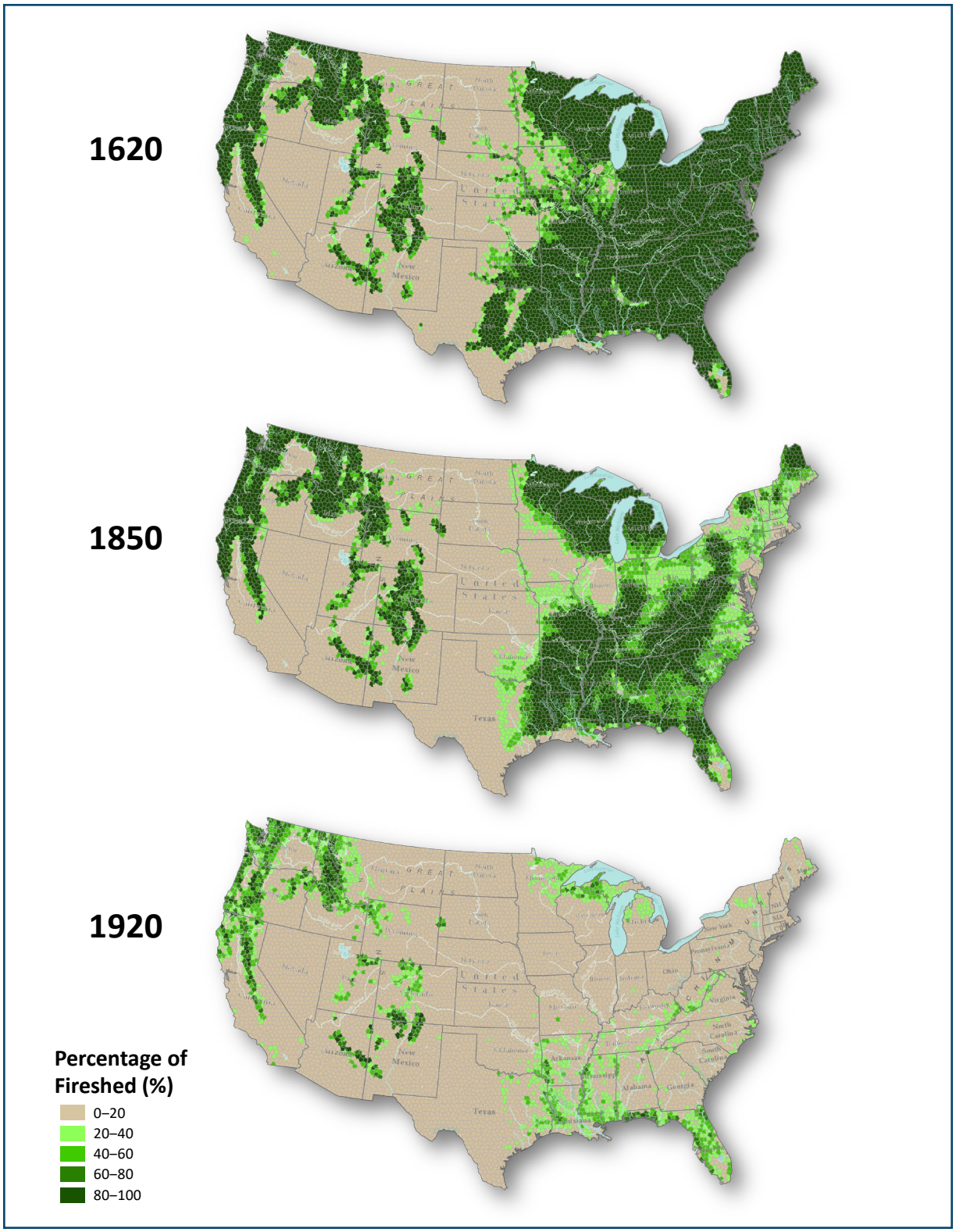


Figure 31.—"It was inevitable that our timber resources should shrink rapidly before this terrific onslaught. The story is told in the maps showing the approximate extent of the virgin forests in 1620, 1850, and 1920." (Greeley 1925). Maps from Greeley (1925) were transcribed onto firesheds as percentage of fireshed and represent all land ownerships.

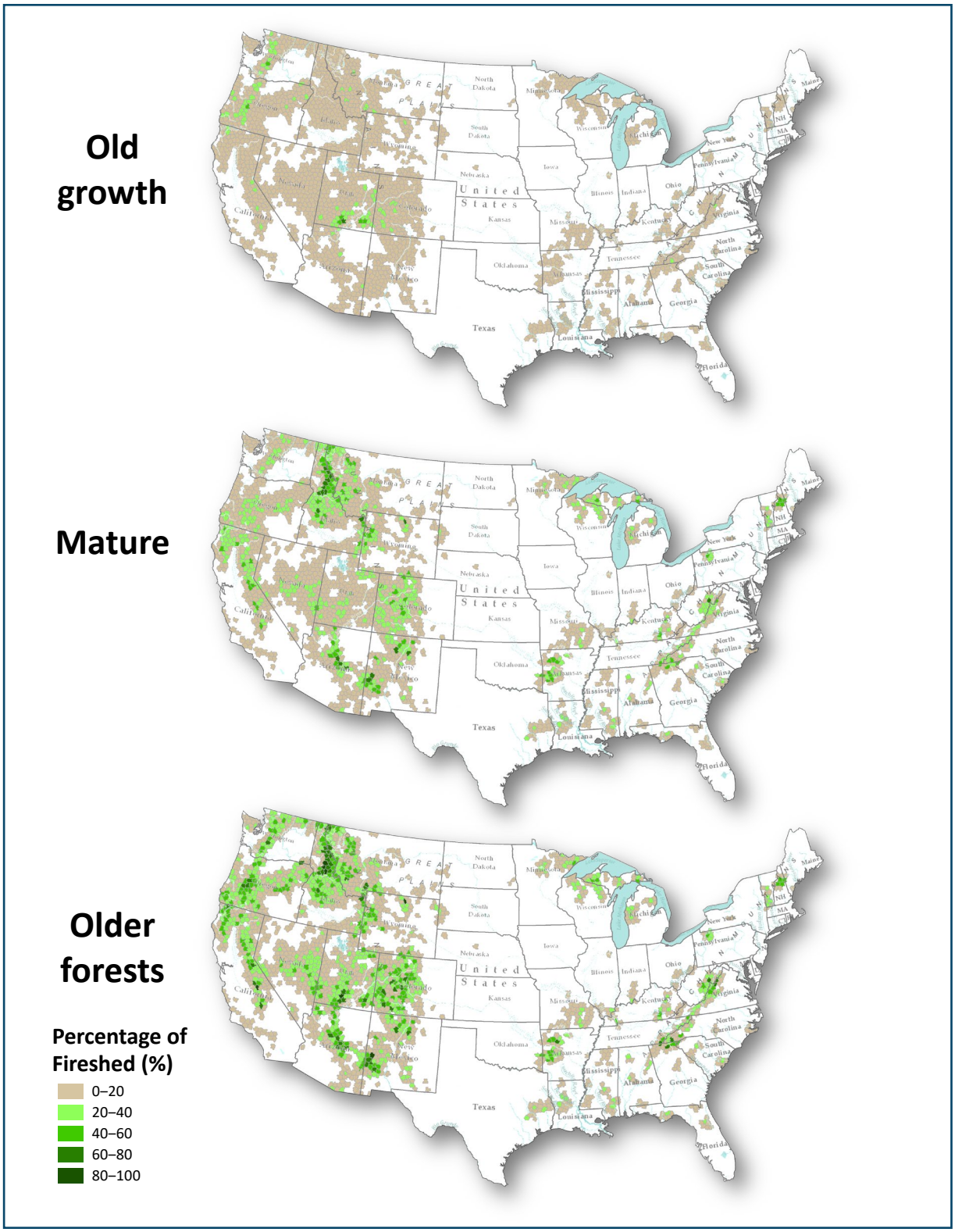


Figure 32.—Fireshed maps of mature and old-growth forests on Forest Service and BLM lands. Old growth (top), mature (middle), and combined (bottom).

Appropriate Use of Data

The contents of this report do not change existing Forest Service and BLM management direction. This rapid analysis was in response to E.O. 14072, is national in scale, and results should not be used at finer spatial scales than recommended in the meta-data of the various analysis products (such as firesheds, project areas). In preparing this report, published scientific and technical literature was reviewed and scientists were consulted about their findings, methods, and/or products. In some instances, they provided advice and technical assistance. The specific results in this report have not been through formal scientific peer reviews, given the time allotted. However, some of the work in this report will be expanded upon and manuscripts prepared for eventual publication in peer-reviewed science journals. The national FIA sample was designed to provide national- and regional-scale estimates. Application of FIA estimates for small areas, with few sample plots, can result in substantial uncertainty. Nationally rare forest conditions, such as old-growth forests in the eastern United States; redwood, riparian forests in arid environments; exotic softwoods; and tropical hardwoods, were not evaluated in this report because there were few or no FIA plots.

Refinements and Opportunities for Future Research

As with the initial mature and old-growth forest inventory report (USDA and USDI 2023), there is ample room for refining the approaches used in this report or to develop new ones. Concurrent with the writing of this report, the Forest Service sent out a request for proposals to a range of research and management agencies and organizations for potential investments to address key knowledge, tool, or technique gaps, or innovation opportunities (with respect to mature and old-growth forest management). Emphasis was placed on:

- Benefits to mature and old-growth forest conservation efforts
- Collaboration between multiple smaller efforts
- Support for monitoring required under the 2012 Planning Rule

Related to methods used in this report, the modified Terrestrial Condition Assessment (MOGCA) can be refined to include Alaska, Hawaii, and the Territories. In addition, development of MOGCA components for future conditions would improve its utility. Research on refugia (climate and fire) are needed to help managers identify the best places to maintain and restore mature and old-growth forests into the future.

Next Steps

The results of this initial mature and old-growth threat analysis, along with the initial mature and old-growth forest inventory report (USDA and USDI 2023), represent the first nationwide assessment of Forest Service and BLM mature and old-growth forests and comprise supporting information for E.O. 14072's requirement to "develop policies, with robust opportunity for public comment, to institutionalize climate-smart management and conservation strategies that address threats to mature and old-growth forests on Federal lands" (Section 2(c).iii). In addition to supporting policy development, the inventory and threat analysis form the foundation for robust, cost-effective broadscale forest monitoring and adaptive management, and inform further Tribal and stakeholder engagement. Steps will be taken to monitor mature and old-growth forests that are not well-represented by FIA plots, such as using remote-sensing. Monitoring will provide context for understanding how local application of management strategies in coordination with Tribes and partners cumulatively contributes to overall persistence and distribution of mature and old-growth, other forest age classes, and the benefits they provide. As the tools and approaches developed for the initial mature and old-growth forest inventory report and threat analysis are refined, and improved with additional information, results will become more timely, cost-effective, and aligned with management needs across scales.

Forest stand managed for public recreation on the Flathead National Forest, Montana. USDA Forest Service photo by Elisa Stamm.

Glossary

Climate change—Changes in average weather conditions (including temperature, precipitation, and risk of certain types of severe weather events) that persist over multiple decades or longer, and that result from both natural factors and human activities, such as increased emissions of greenhouse gases. (source: U.S. Global Change Research Program 2017)

Climatic water deficit—Evaporative demand exceeding available soil moisture computed as the amount of evaporation and plant transpiration that would occur if sufficient water was available minus actual evapotranspiration.

Condition—Current status or state of the characteristic, process, or ecosystem of interest.

Disturbance—Any relatively discrete event in time that disrupts ecosystem, watershed, community, or species population structure and/or function and changes resources, substrate availability, or the physical environment. (source: 36 CFR Part 219.19)

Disturbance regime—A description of the characteristic types of disturbance on a given landscape; the frequency, severity, and size distribution of these characteristic disturbance types; and their interactions. (source: 36 CFR Part 219.19)

Driver—Any natural or human-induced factor that directly or indirectly causes a change in an ecosystem.

Drought—A period of abnormally dry weather long enough to cause a serious hydrological imbalance. (source: U.S. Global Change Research Program 2017)

Ecological integrity—An ecosystem has integrity when its dominant ecological characteristics (for example, composition, structure, function, connectivity, and species composition and diversity) occur within the natural range of variation and can withstand and recover from most perturbations imposed by natural environmental dynamics or human influences. (source: 36 CFR Part 219.19)

Existence value—When people value something even when they do not intend to use or experience it. (source: Krieger 2001)

Exposure—The magnitude or degree of change in climate or other factors a species or system is likely to experience.

Extent—The space or area affected, covered, or described.

Fireshed—A large (approximately 250,000 acre) area where social and ecological concerns about wildfire combine and intertwine. Firesheds are part of a national tessellation of the United States that divide the landscape into similar shaped and sized units. They can serve as analytical units for the assessment of other natural resource management priorities and trends. (source: Ager et al. 2021) https://data.nal.usda.gov/dataset/fireshed-registry-fireshed-and-project-area-boundaries

Forest land—Land at least 10 percent occupied by forest trees of any size or formerly having had such tree cover and not currently developed for nonforest uses. Lands developed for nonforest use include areas for crops, improved pasture, residential or administrative areas, improved roads of any width and adjoining road clearing, and power line clearings of any width. (source: 36 CFR Part 219.19)

Forest type group—Aggregations of forest types into logical ecological groupings (source: Eyre 1980).

Landscape—A defined area irrespective of ownership or other artificial boundaries, such as a spatial mosaic of terrestrial and aquatic ecosystems, landforms, and plant communities, repeated in similar form throughout such a defined area. (source: 36 CFR Part 219.19)

Mature forest— Mature forests are delineated ecologically as the stage of forest development immediately before old growth. Mature forests exhibit structural characteristics that are lacking in earlier stages of forest development and may contain some but not all the structural attributes in old-growth forests. The mature stage of stand development generally begins when a forest stand moves beyond self-thinning, starts to diversify in height and structure, and/or the understory begins to reinitiate. Structural characteristics that mark the transition from an immature to mature forest are unique to each forest type. Characteristics may include but are not limited to abundance of large trees, large tree stem diameter, stem diameter diversity, horizontal canopy openings or patchiness, aboveground biomass accumulation, stand height, presence of standing and/or downed boles, vertical canopy layers, or a combination of these attributes. (source: USDA and USDI 2023)

Mesic—An environment containing a moderate amount of moisture, where soil moisture is available to plants throughout the growing season.

Mesophication—A term used to describe the escalation of mesic microenvironmental conditions accompanied by ever-diminishing prospects for fire and fire-adapted, sun-loving tree species. By altering environmental conditions, shade-tolerant species deter fire through dense shading that promotes moist, cool microclimates and the production of fuels that are not conducive to burning (flaccid, moisture-holding leaf drop; moist, rapidly decaying woody debris). This phenomenon is reinforced and amplified by feedback loops, whereby conditions continually improve for shade-tolerant mesophytic species and further deteriorate for shade-intolerant, fire-adapted species. (source: Nowacki and Abrams 2008)

Old-growth forest—Old-growth forests are dynamic systems distinguished by old trees and related structural attributes. Old growth encompasses the later stages of stand development that typically differ from earlier stages in a variety of characteristics, which may include tree size, accumulations of large dead woody material, number of canopy layers, species composition, and ecosystem function. (source: USDA and USDI 2023)

Project areas—Smaller landscape areas (approximately 25,000-acre) of similar shape and size that are nested within firesheds. (source: Ager et al. 2021) https://data.nal.usda.gov/dataset/fireshed-registry-fireshed-and-project-area-boundaries

Stand—A contiguous group of trees sufficiently uniform in age class distribution, composition, and structure, and growing on a site of sufficiently uniform quality, to be a distinguishable unit, such as mixed, pure, even-aged, and uneven-aged stands. A stand is the fundamental unit of silviculture reporting and record-keeping. (source: USDA Forest Service [N.d.]) https://www.fs.usda.gov/about-agency/regulations-policies/manual/2470-silvicultural-practices

Stakeholder—Any Federal, State, interstate, Tribal, or local agency, any affected nongovernmental organization, affected landowner, or interested person. (source: 18 CFR § 50.1)

Stressor—Factors that may directly or indirectly degrade or impair ecosystem composition, structure, or ecological process in a manner that may impair its ecological integrity, such as an invasive species, loss of connectivity, or the disruption of a natural disturbance regime. (source: 36 CFR 219.19)

Tessellation—An arrangement of shapes closely fitted together, especially of polygons in a repeated pattern without gaps or overlapping.

Threat—A current or projected disturbance or stressor that may contribute to the enduring loss or degradation of the characteristic conditions, functions, or values of existing mature and old-growth forests.

Timber harvesting—The physical cutting and removal of trees or parts of trees from a given forested site. (source: Riddle 2022)

Vulnerability—A function of the sensitivity of a resource or system to exposure, or changes in exposure, to a driver or stressor, and its capacity to adapt to or cope with changes.

Wildfire Crisis Priority Landscape—Firesheds where expanded efforts to reduce wildfire risk will directly benefit at-risk communities and critical infrastructure across 21 landscapes in Arizona, California, Colorado, Idaho, Nevada, New Mexico, Oregon, Utah, and Washington. https://www.fs.usda.gov/sites/default/files/2023-01/wcs-landscapes2-graphics4.jpg

Wildland-urban interface (WUI)—The area where houses meet forests or intermingle with undeveloped wildland vegetation. (source: USDA and USDI 2001)

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Appendixes

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Figure A5.10.—*Mapped condition classes of the Climate Exposure indicator for Project Areas containing federally owned forest land from the MOGCA model. The Climate Exposure indicator depicts how much recent climate conditions have deviated from the historical record. It considers metrics on seasonal temperature, seasonal precipitation, and drought.*

Figure A5.11.—*The number of Project Areas by forest type group and condition class for the Climate Exposure indicator. Nationally, across all forest type groups, 2,247 Project Areas were in Very Poor condition, 2,081 in Poor condition, 2,336 in Moderate condition, 2,573 in Good condition, and 2,542 in Very Good condition.*

Figure A5.12.—*Mapped condition classes of the Drought metric for Project Areas containing federally owned forest land from the MOGCA model. The Drought metric examines MDZ scores over the last three years (2021-2019) compared to the historical record. It is one of 13 metrics considered in the Climate Exposure indicator in the MOGCA model.*

Figure A5.13.—*Mapped condition classes of the Temperature Exposure metrics for Project Areas containing federally owned forest land from the MOGCA model. Temperature Exposure is generated from four seasonal measures (Spring, Summer, Fall, and Winter) that look at average seasonal temperatures over the most recent 5 years (2021-2017) compared to the historical record.*

Figure A5.14.—*Mapped condition classes of the Precipitation Exposure metrics for Project Areas containing federally owned forest land from the MOGCA model. Precipitation Exposure is generated from four seasonal measures (Spring, Summer, Fall, and Winter) that look at average seasonal precipitation amounts over the most recent 5 years (2021-2017) compared to the historical record.*

Figure A5.15.—*Mapped condition classes of the Road indicator for Project Areas containing federally owned forest land from the MOGCA model. The Roads indicators is derived from three roads metrics that capture different road types that vary in their size and volume of traffic: paved roads, light duty roads, and unimproved roads. Roads negatively impact ecological conditions by fragmenting the landscape while also providing conduits for access which is necessary to enable restoration work.*

Figure A5.16.—*The number of Project Areas by forest type group and condition class for the Road Density indicator. Nationally, 3,313 Project Areas were in Very Poor condition, 489 in Poor condition, 632 in Moderate condition, 1,024 in Good condition, and 6,321 in Very Good condition.*

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Figure A5.18.—*Mapped condition classes of the Nitrogen Deposition metric for Project Areas containing federally owned forest land from the MOGCA model. The Nitrogen Deposition metric makes up the Air Quality indicator in the MOGCA model.*

Figure A5.19.—*Mapped condition classes of the Current Threats measure for Project Areas containing federally owned forest land from the MOGCA model. Current Threats are derived from three different potential threats analyzed by the MOGCA model: wildfire, insects and disease, and fire exclusion.*

Figure A5.20.—*The number of project areas by forest type group and condition class for the Current Threat measure which is determined by the scores (outcomes) of the Wildfire Threat to Late Seral Forests, Insect and Disease Hazard, and Fire Deficit indicators in the MOGCA model. Nationally, 5,324 Project Areas were in Very Poor condition, 1,379 in Poor condition, 1,310 in Moderate condition, 1,379 in Good condition, and 2,387 in Very Good condition.*

Figure A5.21.—*Mapped condition classes of the Wildfire Threat to Late Seral Forest indicator for Project Areas containing federally owned forest land from the MOGCA model. This indicator represents the likelihood that fire could cause tree mortality to older forests defined as areas classified as late seral by LANDFIRE Successional Class data.*

Figure A5.22.—*The number of project areas by forest type group and condition class for the Wildfire Threat to Late Seral Forests indicator. Nationally, 2,427 project areas were in Very Poor condition, 636 in Poor condition, 886 in Moderate condition, 1,438 in Good condition, and 6,106 in Very Good condition.*

Figure A5.23.—*Mapped condition classes of the Insect and Disease hazard indicator for Project Areas containing federally owned forest land from the MOGCA model. Insect and Disease hazard leverages the National Insect and Disease Risk Map to determine areas likely to experience significant tree mortality from insects and disease in the next 15 years.*

Figure A5.24.—*The number of Project Areas by forest type group and condition class for the Insect and Disease Hazard indicator. Nationally, 1,960 Project Areas were in Very Poor condition, 752 in Poor condition, 863 in Moderate condition, 1071 in Good condition, and 7,129 in Very Good condition.*

Figure A5.25.—*Mapped condition classes of the Fire Deficit indicator for project areas containing federally owned forest land from the MOGCA model. Fire Deficit is identifying where ecosystems dependent on fire (based on mean fire return intervals) have not had fire at the ecologically appropriate frequency. This deficit is driven predominantly by fire exclusion.*

Figure A5.26.—*The number of Project Areas by forest type group and condition class for Fire Deficit indicator. Nationally, 3,434 Project Areas were in Very Poor condition, 1,420 in Poor condition, 1,282 in Moderate condition, 1,054 in Good condition, and 4,589 in Very Good condition.*

Figure A6.1. —*Region 1 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after a fire disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).*

Figure A6.2.—*Region 2 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after a fire disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).*

Figure A6.3.—*Region 3 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after a fire disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).*

Figure A6.4.—*Region 4 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after a fire disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).*

Figure A6.5.—*Region 5 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after a fire disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).*

Figure A6.6.—*Region 6 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after a fire disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).*

Figure A6.7.—*Region 8 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after a fire disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).*

Figure A6.8.—*Region 9 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after a fire disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).*

Figure A6.9.—*Region 10 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after a fire disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).*

Figure A6.10.—*Regional variations in fire disturbance severity (based on live tree basal area mortality) for mature and old-growth forests. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).*

Figure A7.1.—*A side-by-side visual comparison of the National Burn Probability map (L) with the Anderegg et al. (2022) map (R).*

Figure A7.2.—*Fireshed analysis based on percentage of forests on NFS and BLM lands burned by large (>1,000 ac in the west and 500 ac in the east) moderate- to high-severity fire using Monitoring Trends in Burn Severity (MTBS) data.*

Figure A8.1.—*Resources Planning Act Assessment regions within the contiguous United States.*

Figure A8.2.—*Acres of old growth, mature, and younger forest on Forest Service and Bureau of Land Management land in the contiguous United States until 2070, projected by the Resources Planning Act Assessment Forest Dynamics Model. For each curve, the dark line represents the median projection across 100 replications of the model. The shading represents the interquartile range (middle 50%) of the 100 replications. Note the difference in the scale of the y-axes. Climate models are represented by colors, and results for each scenario are shown in separate panels.*

Figure A8.3.—*Acres of old growth, mature, and younger forest on Forest Service and Bureau of Land Management land by region until 2070, projected by the Resources Planning Act Assessment Forest Dynamics Model, for the high warming/moderate growth scenario only. For each curve, the dark line represents the median projection across 100 replications of the model. The shading represents the interquartile range (middle 50%) of the 100 replications. Climate models are represented by colors. The other three scenarios showed similar trends. Note the difference in the scale of the y-axes on each panel.*

Figure A8.4.—*Annual area burned (in acres) of old growth, mature, and younger forest on Forest Service and Bureau of Land Management land in the contiguous United States until 2070, projected by the Resources Planning Act Assessment Forest Dynamics Model. For each curve, the dark line represents the median projection across 100 replications of the model. The shading represents the interquartile range (middle 50%) of the 100 replications. Climate models are represented by colors, and results for each scenario are shown in separate panels. The secondary y-axis indicates the proportion of total Forest Service and BLM forest land in 2020 that corresponds to the given annual area burned.*

Figure A8.5.—*Annual area burned (in acres) on old growth and mature forest on Forest Service and Bureau of Land Management land by region until 2070, projected by the Resources Planning Act Assessment Forest Dynamics Model, for the high warming/moderate growth scenario only. For each curve, the dark line represents the median projection across 100 replications of the model. The shading represents the interquartile range (middle 50%) of the 100 replications. Climate models are represented by colors. The other three scenarios showed similar trends. Note the difference in the scale of the y-axes for old growth and mature.*

Figure A8.6.—*Annual harvested volume of trees (in cubic feet) from old growth, mature, and younger forest on Forest Service and Bureau of Land Management land in the contiguous United States until 2070, projected by the Resources Planning Act Assessment Forest Dynamics Model. For each curve, the dark line represents the median projection across 100 replications of the model. The shading represents the interquartile range (middle 50%) of the 100 replications. Climate models are represented by colors, and results for each scenario are shown in separate panels. The secondary y-axis indicates the proportion of total live volume on Forest Service and BLM forest land in 2020 that corresponds to the given annual removal volume.*

Figure A8.7.—*Annual harvested volume of trees (in cubic feet) from old growth and mature forest on Forest Service and Bureau of Land Management land by region until 2070, projected by the Resources Planning Act Assessment Forest Dynamics Model, for the middle climate model (NorESM1-M) only. For each curve, the dark line represents the median projection across 100 replications of the model. The shading represents the interquartile range (middle 50%) of the 100 replications. The other climate models showed similar trends.*

Figure A9.1.—*Region 1 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after an insect/disease disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).*

Figure A9.2.—*Region 2 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after an insect/disease disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).*

Figure A9.3.—*Region 31 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after an insect/disease disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).*

Figure A9.4.—*Region 4 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after an insect/disease disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).*

Figure A9.5.—*Region 5 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after an insect/disease disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).*

Figure A9.6.—*Region 6 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after an insect/disease disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).*

Figure A9.7.—*Region 8 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after an insect/disease disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).*

Figure A9.8.—*Region 9 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after an insect/disease disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).*

Figure A9.9.—*Region 10 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after an insect/disease disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).*

Figure A9.10.—*Regional variations in insect/disease disturbance severity (basal area mortality) for mature and old-growth forests. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).*

Figure A10.1.—*Region 1 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after a weather disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance*

severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).

Figure A10.2.—*Region 2 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after a weather disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).*

Figure A10.3.—*Region 3 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after a weather disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).*

Figure A10.4.—*Region 4 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after a weather disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).*

Figure A10.5.—*Region 5 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after a weather disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).*

Figure A10.6.—*Region 6 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after a weather disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).*

Figure A10.7.—*Region 8 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after a weather disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).*

Figure A10.8.—*Region 9 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after a weather disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).*

Figure A10.9.—*Region 10 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after a weather disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).*

Figure A10.10.—*Regional variations in weather disturbance severity (basal area mortality) for mature and old-growth forests.*

Figure A11.1.— *Stakeholder responses to the term 'tree cutting' illustrate the complexity of perspectives on the subject.*

Figure A12.1.—*Region 1 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after a tree cutting disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).*

Figure A12.2.—*Region 2 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after a tree cutting disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance*

severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).

Figure A12.3.—*Region 3 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after a tree cutting disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).*

Figure A12.4.—*Region 4 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after a tree cutting disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).*

Figure A12.5.—*Region 5 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after a tree cutting disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).*

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Figure A12.7.—*Region 8 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after a tree cutting disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).*

Figure A12.8.—*Region 9 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after a tree cutting disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).*

Figure A12.9.—*Region 10 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after a tree cutting disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).*

Figure A12.10.—*Regional variations in tree cutting disturbance severity (basal area mortality) for mature and old-growth forests. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).*

Figure A13.1.—*Region 1 net changes (with 95-percent confidence intervals) to mature and old-growth forest acres based on remeasured Forest Inventory and Analysis (FIA) plots ordered (from left to right) by largest net losses to largest net gains. Percentages are mean net changes. Asterisks (*) indicate a statistically significant net change.*

Figure A13.2.—*Region 2 net changes (with 95-percent confidence intervals) to mature and old-growth forest acres based on remeasured Forest Inventory and Analysis (FIA) plots ordered (from left to right) by largest net losses to largest net gains. Percentages are mean net changes. Asterisks (*) indicate a statistically significant net change.*

Figure A13.3.—*Region 3 net changes (with 95-percent confidence intervals) to mature and old-growth forest acres based on remeasured Forest Inventory and Analysis (FIA) plots ordered (from left to right) by largest net losses to largest net gains. Percentages are mean net changes. Asterisks (*) indicate a statistically significant net change.*

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Figure A13.7.—*Region 8 net changes (with 95-percent confidence intervals) to mature and old-growth forest acres based on remeasured Forest Inventory and Analysis (FIA) plots ordered (from left to right) by largest net losses to largest net gains. Percentages are mean net changes. Asterisks (*) indicate a statistically significant net change.*

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Tables

Table A4.1.—*Characteristics of sample plots on BLM and Forest Service lands used in the FIA plot change analysis, showing evaluations (EVALIDs), inventory years, mean plot remeasurement interval, and number of forested plots used.*

Table A5.1.—*Parameters used in the Mature and Old Growth Condition Assessment.*

Table A5.2.—*Indicators and metrics used in the Mature and Old Growth Condition Assessment and associated data sources.*

Table A5.3.—*Ranges of continuous scores used to define the condition and threat classes used to characterize output scores from the Mature and Old Growth Condition Assessment (MOGCA) model. Good (poor) ecological conditions are aligned with lower (higher) threats.*

Table A7.1.—*Map class thresholds for the continuous model outputs for the National BP and Anderegg maps.*

Table A7.2.—*Proportion (total and averaged annually) of NFS and BLM forest burned by moderate to high-severity wildfires. Historical data for Monitoring Trends in Burn Severity only extends back to 1984.*

Appendix 1 – Recent Government Actions

Executive Order 14072

On April 22, 2022, **E.O. 14072 (also known as "Strengthening the Nation's Forests, Communities, and Local Economies")[1] instructed the Department of the Interior, Bureau of Land Management (BLM) and U.S. Department of Agriculture (USDA), Forest Service to implement a set of actions focused on the health of the Nation's forests.** This Executive order focuses on the role of mature and old-growth forests on Federal lands in supporting healthy, prosperous, and resilient human communities. It directs the Secretary of the Interior and the Secretary of Agriculture, to:

1. Define, identify, and complete an inventory of mature and old-growth (MOG) forests on Federal lands, accounting for regional and ecological variations, as appropriate.
2. Coordinate conservation and wildfire risk reduction activities, including consideration of climate-smart stewardship of MOG forests, with other executive departments and agencies, States, Tribal Nations, and any private landowners who volunteer to participate.
3. Analyze the threats to MOG forests on Federal lands, including from wildfires and climate change.
4. Develop policies, with robust opportunity for public comment, to institutionalize climate-smart management and conservation strategies that address threats to MOG forests on Federal lands.

Threats to MOG forests specifically mentioned in the Executive order included wildfire (specifically catastrophic), decades of fire exclusion, insect infestations, disease, and climate change.

USDA Secretary's Memo 1077-004

On June 23, 2022, this memo titled **Climate Resilience and Carbon Stewardship of America's National Forests and Grasslands[2]** (issued by the Secretary of Agriculture) highlighted that climate impacts, in combination with a legacy of fire exclusion and other past management practices, have already caused severe disruptions in natural forest ecosystems. As an example, in fire-frequent forests, more than a century of fire exclusion has caused them to become significantly different from their natural structural/compositional conditions and more vulnerable to uncharacteristic and catastrophic wildfire. The climate crisis is exacerbating unhealthy forest conditions through widespread drought, insect and disease mortality, and an increase in extreme weather events. It stated that timber harvesting was once a primary threat to old-growth forests on national forests but is no longer a threat compared to catastrophic wildfires and other disturbances resulting from the combination of climate change and past fire exclusion as discussed above. This memo stated that *"The appropriate science-based practices that will sustain resilient forests and stabilize forest carbon are place specific,"* and it called for spatially identifying risks to ecosystem values to inform

[1] https://www.whitehouse.gov/briefing-room/presidential-actions/2022/04/22/executive-order-on-strengthening-the-nations-forests-communities-and-local-economies/
[2] https://www.usda.gov/directives/sm-1077-004

decision making. Following completion of the MOG forest inventory report in response to E.O. 14072, Section 2(b), the memo recommended measures to protect, maintain, restore, and cultivate MOG forests within the National Forest System, grounded in science, considering a range of management strategies, and recognizing complementary opportunities and tradeoffs with other ecosystem values including water, wildlife, and biodiversity and social values such as wildfire risk to communities and source-water watersheds.

Tribal and Alaska Native Corporations Consultation

In December 2022, Government-to-Government consultation was initiated and will continue throughout the agencies' response to Section 2(b) and Sections 2(c).ii and 2(c).iii of E.O. 14072. Consultation on actions may be requested at any time and the timelines for consultation on those actions will be made available as they arise. Consultation will remain open and ongoing throughout the entire effort.

Proposed Rule on Conservation and Landscape Health

On April 3, 2023, the BLM published a proposed rule that gave the public an opportunity to comment on proposed new regulations to ensure the health and resilience of BLM lands. The proposed Public Lands Rule focuses on protecting intact landscapes, restoring degraded habitat, and making wise management decisions based on science and data. It is designed to ensure healthy wildlife habitat, clean water, and ecosystem resilience so public lands can resist and recover from disturbances like drought and wildfire. The notice for the proposed rule stated that pursuant to E.O. 14072, the BLM is working on various aspects of ensuring that forests on BLM lands, including old and mature forests, are managed to: promote their continued health and resilience; retain and enhance carbon storage; conserve biodiversity; mitigate the risk of wildfires; enhance climate resilience; enable subsistence and cultural uses; provide outdoor recreational opportunities; and promote sustainable local economic development. Questions it posed to the public included "What additional or expanded provisions could address this issue in this rule?" and "How might the BLM use this rule to foster ecosystem resilience of old and mature forests on BLM lands?"

In response to these questions, many comments were received emphasizing the need to protect old-growth and mature forests as part of meeting the proposed rule's stated purpose of ensuring ecosystem resilience on public lands. Commenters recommended adding provisions to the rule to establish emphasis areas for old-growth and mature forests, limit or prohibit tree cutting on BLM-managed lands, facilitate designation of old-growth forests as Areas of Critical Environmental Concern (ACECs), and focus on climate sustainable logging. Commenters highlighted the scientific and social values of old-growth and mature forests and requested explicit language in the rule to protect these valuable ecosystems consistent with E.O. 14072. BLM published the final rule on May 9, 2024, with an effective date of July 10, 2024.[3]

[3] https://www.federalregister.gov/documents/2024/05/09/2024-08821/conservation-and-landscape-health

The Mature and Old-Growth Forest Inventory

On April 21, 2023, the Forest Service and BLM released a technical report on the definitions, identification, and initial inventory of mature and old-growth forests on National Forest System and BLM forestlands (revised April 2024)[4] (USDA and DOI 2023—hereafter, referred to as the mature and old-growth forest inventory report). This report was the product of E.O. 14072, Section 2(b) and is the first national inventory of mature and old-growth forests on National Forest System (NFS) and BLM forestlands. It documented that these forests are generally widely distributed geographically and across Congressional designated land use allocations. A definitional framework led to detailed quantitative criteria, using measurable structural characteristics that were applied to specific regions and forest types. Applying these criteria to Forest Inventory and Analysis (FIA) field plot data, NFS and BLM forestlands collectively contain 33.1 +/- 0.4 million acres of old-growth and 80.8 +/- 0.5 million acres of mature forest, at a 68-percent confidence interval. Old-growth forest represents 19 percent and mature forest another 45 percent of all forested land managed by the two agencies. To address the Secretary's memo "place specific" direction, FIA estimates were produced for firesheds that contained NFS and BLM forestlands (see glossary). This effort produced peer reviewed scientific publications documenting the methods developed and used for this inventory (Gray et al. 2023, Pelz et al. 2023, Woodall 2023).

Advance Notice of Proposed Rulemaking

Also in April 2023, the Forest Service published an Advance Notice of Proposed Rulemaking (ANPR). The ANPR gave the public an opportunity to explore new tools, like the Climate Risk Viewer (web link), and to provide input on how the Forest Service should respond to the climate crisis through management activities and possibly future policies. It included the following two questions specifically informing outcomes of E.O. 14072:

1. How might the Forest Service use the mature and old-growth forest inventory—together with analyzing threats and risks—to determine and prioritize when, where, and how different types of management will best enable retention and expansion of mature and old-growth forests over time?
2. Given our current understanding of the threats to the amount and distribution of mature and old-growth forest conditions, what policy, management, or practices would enhance ecosystem resilience and distribution of these conditions under a changing climate?

Based on initial analysis of the 92,000 public submissions, protections for mature and old-growth forests were the most commonly expressed statement. Recommendations included a temporary moratorium on logging until longer-term conservation and management strategies have been established. Other submissions indicated that MOG forests should not be actively managed and should be "chainsaw free, livestock free, connected, and fire inclusive and should be protected from logging, mining, grazing, and oil and mineral development." Several submissions recommended special designations to ensure protection of MOG forests, including designation as carbon reserves. Analysis of comments and refinement of recommendations is ongoing.

[4] https://www.fs.usda.gov/sites/default/files/fs_media/fs_document/Mature-and-Old-Growth-Forests.pdf

Appendix 2 – Forums and Engagements

Throughout July 2023, the Forest Service and BLM conducted eight meetings to systematically engage more than 600 Forest Service and BLM employees and an estimated 170 members of the general public, 70 advocacy group members, 70 scientists, 60 other government employees, 60 industry members, and about 20 people from other user groups. Almost 1,000 people learned and shared their views about the MOG initiative. The sessions were an opportunity for participants to share thoughts and concerns and to ask questions.

The engagement sessions focused on the MOG threat analysis framework provided findings from the forest inventory report and information about its future refinement. Robust engagement and individual conversations with stakeholders resulted in vigorous and often competing narratives.

Based on engagement feedback, additional data layers (for example, timber mill infrastructure, adjacent land use change, source watersheds) were considered. It was also suggested that threat identification and management implementation would be helped by spatially providing MOG inventory at a finer spatial scale. Several potential partnerships in collaboration with the agencies are examining approaches that might provide greater granularity for the MOG inventory. Additionally, as outlined in the forest inventory report, Forest Service regions and districts will apply other approaches to operationalize the Forest Inventory and Analysis-based national inventory. Participant feedback illustrated that it will be important for the threat analysis report to show that a system driver or stressor can be one person's threat and another person's solution, depending on the forest ecosystem and the individual's priorities and perceptions. The following are some highlights of feedback received:

- **Timber Harvest and Active Forest Management**
    - Place a moratorium on all MOG harvesting to better retain and enhance carbon sequestration and storage.
    - Retain and enhance carbon storage, while continuing to harvest MOG.
    - Timber harvesting is the only threat to MOG that we can control, and we should stop doing it.
    - Analyze timber harvest and other forms of active forest management as a threat.
    - Harvesting is not a threat to MOG, continue to produce lumber domestically.
    - A policy would have a negative impact on rural forest-based communities.
    - A policy might impact resource use and timber output.
- **Fire**
    - Fire is a benefit to MOG conservation, not a threat.
    - Fire suppression compromises forest resiliency and MOG.
    - Fire is the biggest threat to MOG.
    - Prescribed fire and backburns are widely used without considering the impact on MOG and so consume significant acres of MOG.

- **Carbon Storage and Emissions**
    - Harvesting, and the roads required, increase carbon emissions, reduce carbon storage, and increase the likelihood of wildfires.
    - MOG sequesters and stores the most carbon.
    - Young vigorous forest store carbon more quickly.
    - Wood products play an important role in sequestering carbon.
- **Tribal and Cultural**
    - Integrate Western science and Indigenous Knowledge.
    - Inform and work with Tribes and Alaska Native Corporations.
    - Co-stewardship is important.
- **Threats**
    - Natural disturbances, policies that restrict MOG treatment pace and scale, timber harvest, anthropogenic activities (for example, logging, prescribed burns, plantation management, roads), and nonnative species encroachment are threats to MOG.
    - Activities on State and private lands adjacent to Forest Service and BLM lands are threats.
    - Expansion of the wildland-urban interface is a threat to MOG.
- **Special Designations/Protections**
    - Designations to meet 30x30 Executive Order 14008 are needed.
- **Forest Service Land Management Plans and BLM Resource Management Plans**
    - Management plan guidance conflicts with ANPR and mature and old-growth forest initiative.
    - Use the results of the initial MOG inventory during forest and project planning to support diverse ecosystems.
    - Use management plans to manage, monitor, and adapt MOG management.
    - There would be no issues if management plans were fully implemented.

Attendees at the engagement sessions were also asked to answer two questions about MOG benefits and threats. While not a random sample, asking the questions provided an additional opportunity for feedback. Nearly 200 Forest Service and BLM employees, more than 30 members of the public, and less than 20 members each from the other attendee groups provided answers. Overall, stakeholders most frequently named ecological processes, habitat, ability to store and sequester carbon, and recreation as benefits from MOG. The most commonly mentioned threats were logging, improper/lack of management, climate change, and wildfire. Generally, Forest Service and BLM employees identified wildfire, insects and disease, and climate change as the biggest threats to MOG.

Forest Service and BLM employees were asked a slightly different second question than that asked of stakeholders. Employees were asked to comment on what they see as challenges to managing

MOG. Communication with the public and public perceptions as well as litigation, appeared most frequently. There were also numerous responses about shortcomings in planning tools, lack of planning clarity/agreement, restrictions on management, and mismanagement.

Tribal and Alaska Native Corporations Forum

On July 12, 2023, the Forest Service held a Tribal and Alaska Native Corporation forum on the agency's implementation of the **Advanced Notice of Proposed Rulemaking** *Climate Resilient Forests and Grasslands*, **Secretarial Memo 1077-004** *Climate Resilience and Carbon Stewardship of America's National Forests and Grasslands*, and **Executive Order 14072** *Strengthening the Nation's Forests, Communities, and Local Economies*. Representatives from the National Forest System spent approximately 2 hours sharing information on all 3 topics followed by a discussion. The following is some of the key feedback that was received:

Several Tribal organizations, working groups, efforts, and/or initiatives focus on climate change. The agency should consider engaging with these efforts, connecting Tribal and Forest Service scientists to inform climate change approaches and policies:

- Active engagement with individual Tribes is essential to the respectful application of Indigenous Knowledge.
- Engagements should occur at the most local level possible and local relationships should be prioritized.
- Non-timber forest products (for example, food systems) are important and must be prioritized in addition to timber.
- Data sovereignty must also be addressed and incorporated as Indigenous Knowledge is incorporated into policy and climate change resilience practices.
- The Forest Service should clarify the definition being used for Indigenous Knowledge.
- Clarity is needed on how the agency will consider and account for the breadth, depth, and diversity of Indigenous Knowledges within policy.

Responses from Forest Service panelists included the following:

- The agency sponsored Tribal roundtables in winter 2023/spring 2024 for Tribal representatives to interact with each other and dialogue around appropriate application of Indigenous Knowledge—as well as commonalities and differences in Indigenous Knowledges.
- Mature forests are the 'clay' with which to sculpt old growth. The agency is seeking a deeper understanding of how to mold that clay through active engagement with Tribal leaders and people scaled to local levels. The term 'accountability to place' resonated with the agency panelists.
- Forest Service panelists agreed that early and meaningful InterTribal engagement with Tribes and community members is an important factor in relationship building, and this

needs to be accounted for in policy and project development. Creating national policies, approaches, and expectations that drive interactions at the local level is a critical task.

- The Forest Service has and will continue to encourage local Native-led groups as they work to develop climate adaptation menus by making expectations clear at the national level.
- If the effort moves forward into a proposed rule and Indigenous Knowledge is included as a definition, the agency wants to ensure that Tribal perspectives are incorporated and wants to address diversity in Indigenous Knowledges.
- Addressing Tribal data sovereignty is an important part of incorporating Indigenous Knowledge and Western science. The agency must be respectful of Tribal sovereignty in data management.
- The Forest Service is recruiting Tribal youth professionals to help braid together Indigenous Knowledge and Western science.
- To help further connections, establishing a Native American Advisory Committee that includes Tribal subject matter experts at all levels of the agency, should be considered.

The Forest Service and BLM held informational engagement sessions in November 2023 that focused on work associated with analyzing threats to mature and old-growth forests to support policy development to reduce those threats and foster climate resilience. A Tribal forum to share the same information was held in December 2023.

Appendix 3 – Regional Condition-Based Evaluation Worksheets

Forest Service regions provided condition-based information using threat evaluation worksheets and templates:

Instructions were to provide brief general descriptions in worksheets (fFigure A3.1) by region (Figure A3.2), ecological division (Figure A3.3), and forest type group (Figure A3.4):

- How extensive compared to other types;
- Xeric, mesic, moist;
- Most common tree species;
- Drivers critical to maintaining system;
- Environmental history (such as broad-scale clearcutting in the early 1900s) resulting in extensive, low-diversity mature forest;
- What social, cultural, and economic benefits are provided by this forest type? Benefits may not be solely dependent on forest type and are not necessarily uniformly distributed across a forest. Examples include, but are not limited to:
    - Tribal rights/practices (including hunting, fishing, gathering), cultural and spiritual sites;
    - Sustain rural ways of life and bases of income (for example, forage for domestic livestock, grazing, ranching);
    - Timber or biomass for sale;
    - Recreation and tourism, trail systems, aesthetics and scenery, existence value (valuing that the resource does and will continue to exist);
    - Passive human benefits (for example, carbon sequestration, climate regulation, filtration of fresh water provided to downstream uses);
    - Cultural sites, heritage, sense of place;
    - Opportunities for education and knowledge;
    - Public health (physical and/or mental), environmental quality, social relationships/spaces for interaction;
    - Include most important source citations (not exhaustive). Can be from expertise/observation, monitoring reports, literature, interfacing with the public, etc.
- Include most important literature citations (not exhaustive). Can be from expertise/observation, monitoring reports, literature, interfacing with the public, etc.

Threat Evaluation
Record Adverse outcome criteria: change condition renders forest non-mature or non-old growth forest

Forest Vegetation Threat Evaluation: Region# ***VEGETATION TYPE***

USER FORM

FIA Forest Type Group:

Forest Service EcoMap Divisions:

Brief General Description of this vegetation:

Driver/ Stressor	Narratives	Sources
1st Driver/Stressor Example: Fire (including wildfire of all intensity, cultural burning, and other forest treatments employing fire	General Description of driver/stressor • Emphasis on disturbance processes (fine or broad scale) that influence mature/old-growth conditions across areas of one or more stands • Frequency, Severity • Primary influence on composition, structure • Examples of well-documented social/cultural linkages to old-growth forest type • Disturbances likely to influence non-dominant species (trees or others) and NOT result in changed status (still old-growth forest) • How are the social, cultural, or economic benefits identified in the 'Brief General Description' section impacted by this driver/stressor?	For example, (Jones 2010)
	Conditions determining negative (adverse) outcome • Describe features of this disturbance agent that lead to negative outcomes • Describe forest conditions that contribute to negative outcomes • Describe interactions with other disturbance agents that contribute to negative outcomes • Describe any social, cultural, or economic conditions that can or do contribute to negative outcomes	
	Conditions determining positive or neutral outcome • Describe features of this disturbance agent that improve conditions for MOG or reduce vulnerability • Describe forest conditions that that improve conditions for MOG or reduce vulnerability • Describe interactions with other disturbance agents that contribute to positive or neutral outcomes • Describe any social, cultural, or economic conditions that can or do contribute to a neutral or positive outcome	
	Summary of relative importance of this driver/stressor as a threat:	
	Summary of relative importance of this driver/stressor in restoration/transformation:	
Evaluator(s): Reviewer(s):		Date:

Literature Cited

Figure A3.1.—Example of worksheet used to document regional inputs.

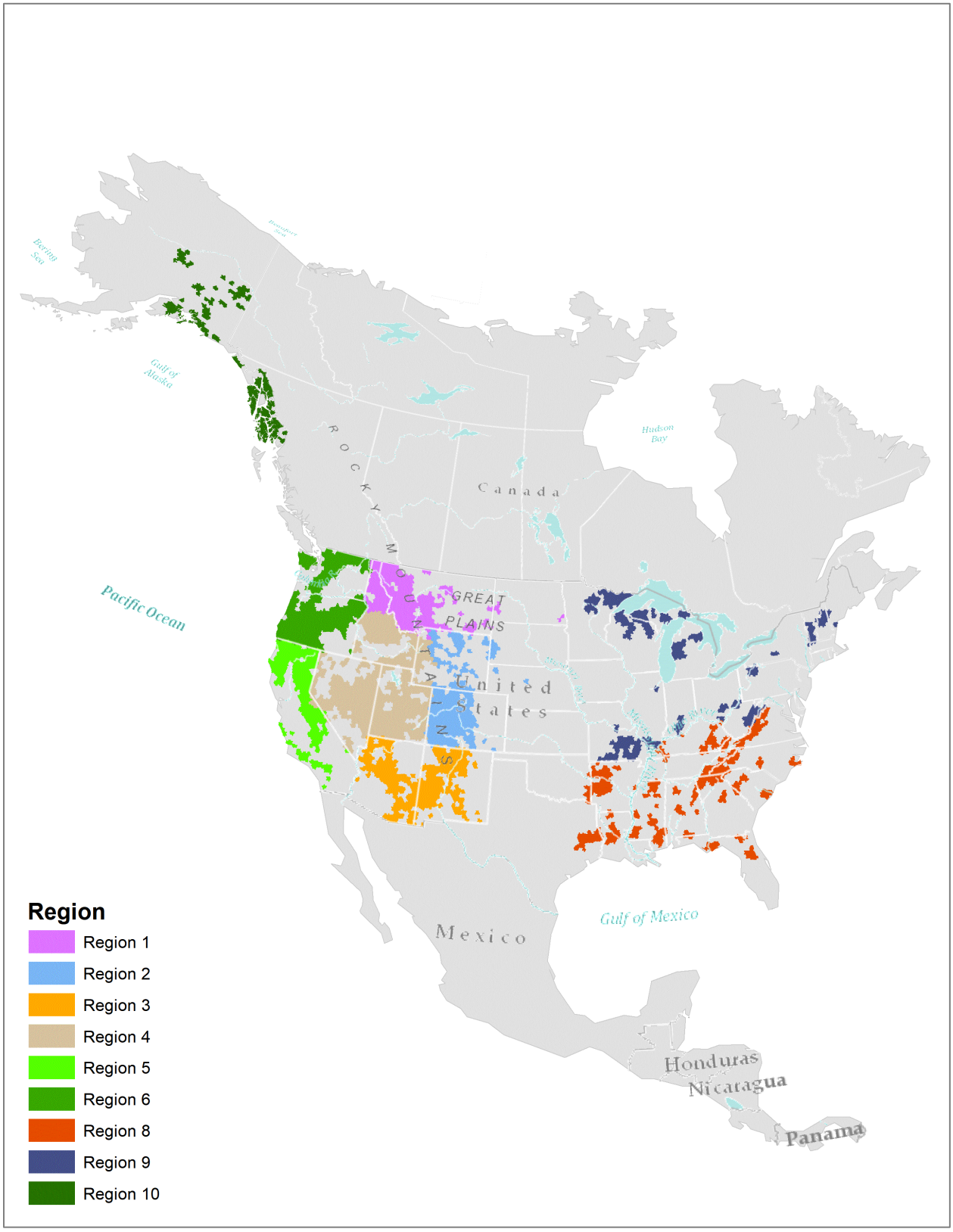


Figure A3.2.—Fireshed map of regions.

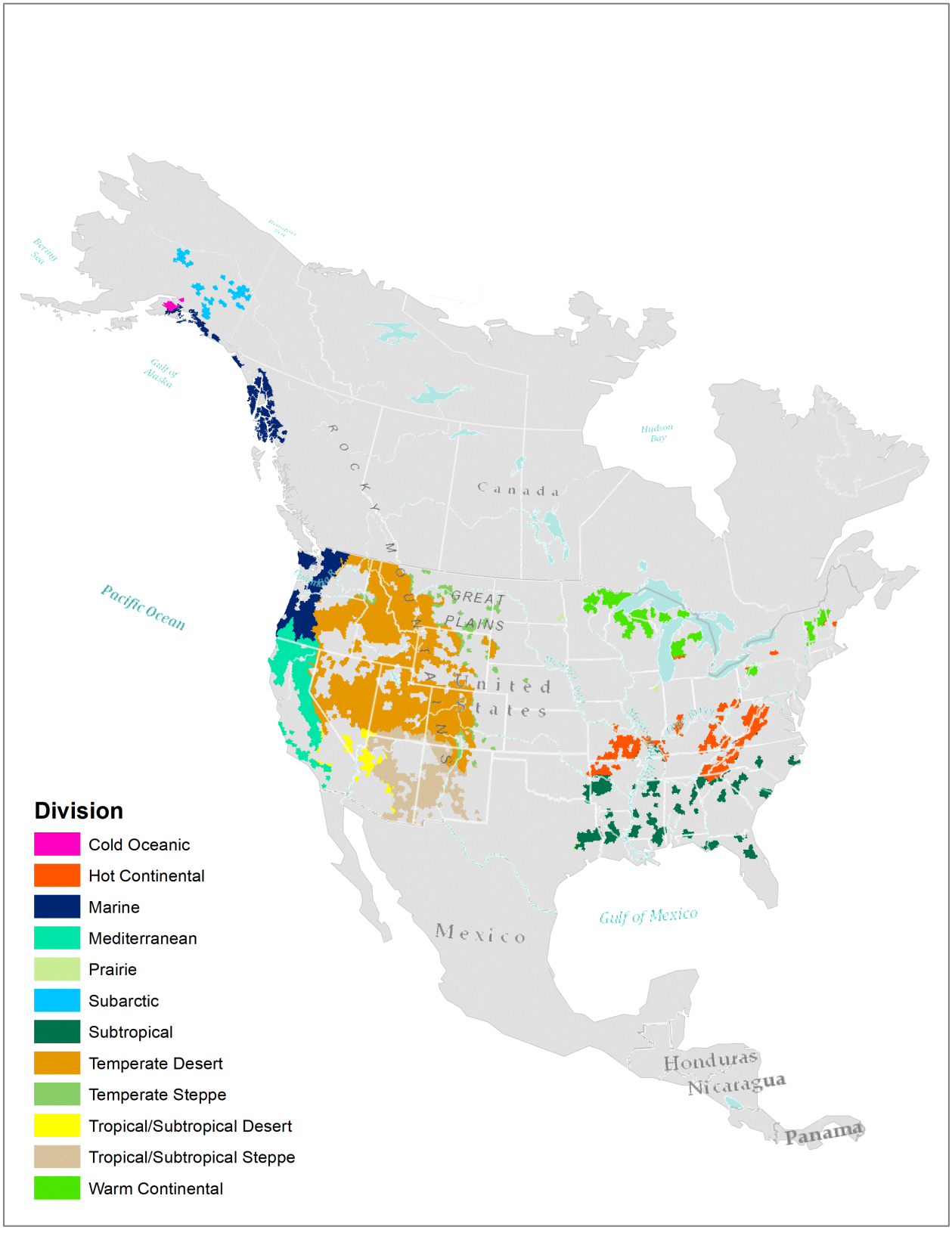


Figure A3.3.—Fireshed map of ecological divisions.

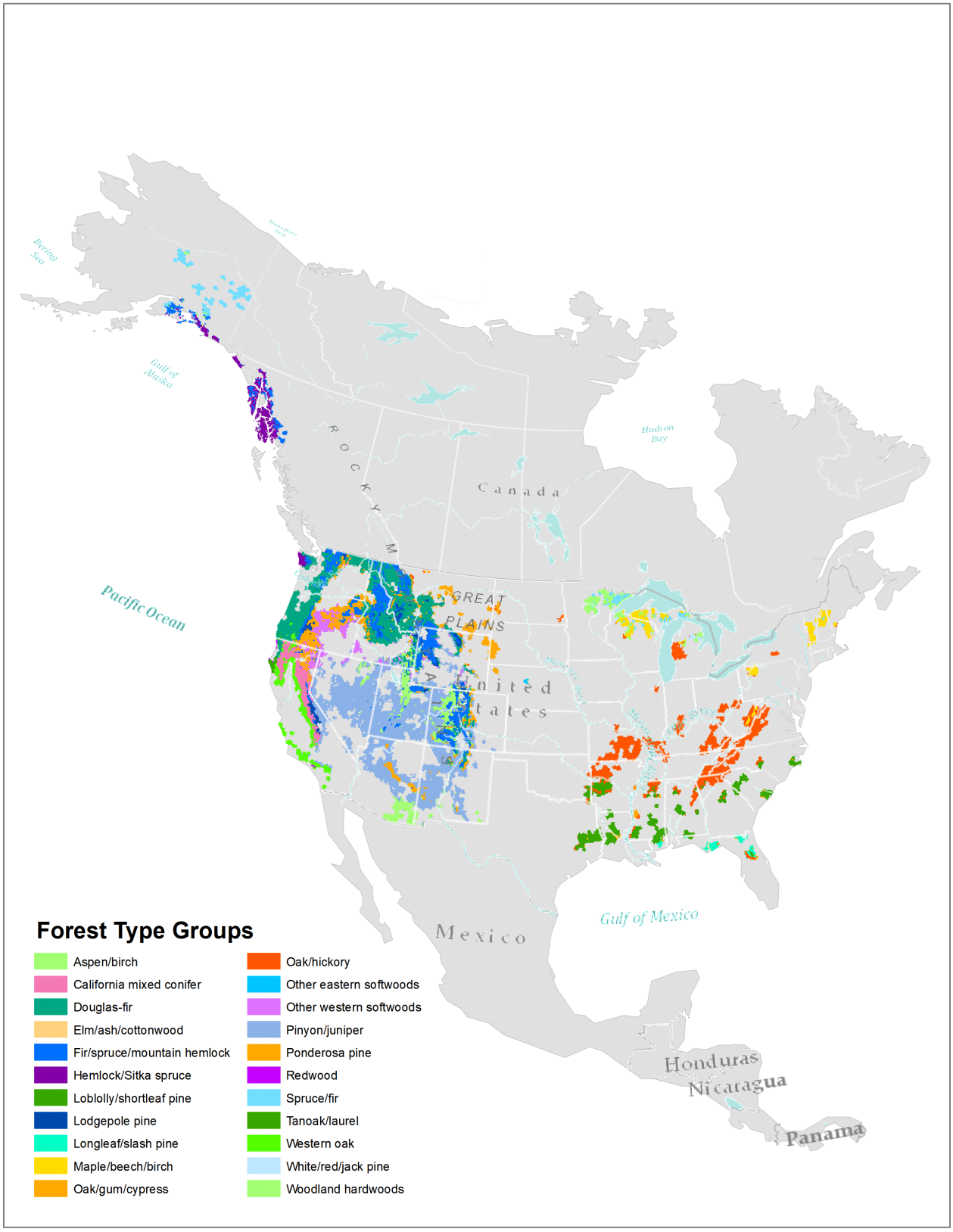


Figure A3.4.—Fireshed map of forest type groups.

Appendix 4 – Forest Inventory Analysis Sample Plot Characteristics

Table A4.1.—Characteristics of sample plots on BLM and Forest Service lands used in the FIA plot change analysis, showing evaluations (EVALIDs), inventory years, mean plot remeasurement interval, and number of forested plots used.

STATECD	State_name	EVALID	First measurement	Remeasurement	Mean remeasurement period (years)	N plots
1	Alabama	12103	2006 - 2017	2014 - 2021	6.8	124
2	Alaska (coastal)	21903	2004 - 2008	2015 - 2019	11.2	528
4	Arizona	41903	2001 - 2009	2011 - 2019	10.1	1,322
5	Arkansas	52103	2012 - 2016	2017 - 2021	5.2	413
6	California	61903	2001 - 2009	2011 - 2019	10.0	2,332
8	Colorado	81903	2002 - 2009	2012 - 2019	10.0	1,987
9	Connecticut	92003	2009 - 2013	2014 - 2020		0
10	Delaware	102003	2009 - 2013	2014 - 2020		0
12	Florida	121903	2010 - 2016	2015 - 2019	6.1	348
13	Georgia	132003	2011 - 2017	2016 - 2020	5.5	373
16	Idaho	161903	2004 - 2009	2014 - 2019	9.9	1,647
17	Illinois	172103	2009 - 2014	2015 - 2021	6.1	151
18	Indiana	182003	2009 - 2013	2014 - 2020	5.9	82
19	Iowa	192103	2009 - 2014	2015 - 2021		0
20	Kansas	202003	2009 - 2013	2014 - 2020		0
21	Kentucky	211803	2005 - 2012	2012 - 2018	6.1	127
22	Louisiana	221803	2001 - 2012	2009 - 2018	8.3	111
23	Maine	232103	2012 - 2016	2017 - 2021	5.0	26
24	Maryland	241903	2008 - 2013	2013 - 2019		0
25	Massachusetts	251903	2008 - 2013	2013 - 2019		0
26	Michigan	261903	2008 - 2013	2013 - 2019	5.9	989
27	Minnesota	271903	2010 - 2014	2015 - 2019	5.0	705
28	Mississippi	282003	2009 - 2015	2016 - 2020	6.8	535
29	Missouri	292103	2009 - 2014	2015 - 2021	6.2	493
30	Montana	301903	2003 - 2009	2013 - 2019	10.0	1,806
31	Nebraska	312003	2009 - 2013	2014 - 2020	6.2	8
32	Nevada	321903	2004 - 2009	2014 - 2019	8.6	948
33	New Hampshire	332003	2009 - 2014	2014 - 2020	6.1	258
34	New Jersey	341903	2009 - 2014	2015 - 2019		0
35	New Mexico	351903	2005 - 2009	2015 - 2019	6.8	819
36	New York	361903	2008 - 2013	2013 - 2019	6.2	5
37	North Carolina	372103	2009 - 2015	2016 - 2021	6.6	210
38	North Dakota	382103	2009 - 2014	2015 - 2021	6.3	15

STATECD	State_name	EVALID	First measurement	Remeasurement	Mean remeasurement period (years)	N plots
39	Ohio	391903	2008 - 2013	2013 - 2019	5.8	70
40	Oklahoma	401903	2009 - 2014	2015 - 2019	6.0	53
41	Oregon	411903	2001 - 2009	2011 - 2019	10.0	6,174
42	Pennsylvania	422003	2009 - 2013	2014 - 2020	6.1	187
44	Rhode Island	442003	2009 - 2013	2014 - 2020		0
45	South Carolina	452003	2007 - 2016	2014 - 2020	5.4	279
46	South Dakota	462003	2009 - 2013	2014 - 2020	6.0	176
47	Tennessee	471803	2005 - 2014	2012 - 2018	6.6	309
48	Texas	481903	2004 - 2014	2014 - 2019	5.5	308
49	Utah	491903	2000 - 2009	2010 - 2019	10.0	2,025
50	Vermont	502003	2009 - 2013	2014 - 2020	6.1	154
51	Virginia	512003	2009 - 2015	2015 - 2020	5.3	464
53	Washington	531903	2002 - 2009	2012 - 2019	10.0	2,573
54	West Virginia	542003	2009 - 2013	2014 - 2020	6.0	342
55	Wisconsin	552103	2009 - 2014	2015 - 2021	6.2	528
56	Wyoming	Custom	2000 - 2000	2011 - 2019	15.2	859
72	Puerto Rico	721903	2011 - 2014	2016 - 2019	5.8	2
78	Virgin Islands of the U.S.	781403	2009 - 2009	2014 - 2014		0
	All				9.0	30,864

Appendix 5 – Mature and Old Growth Condition Assessment Description and Results

Model Description

Scientific review, public engagement, and employee dialogue identified numerous stressors and drivers that—under certain conditions—become threats to the resilience and persistence of MOG forests. While it is important to identify individual stressors and drivers along with their historical trends, current conditions, and future projections, it is also important to understand how these stressors and drivers co-occur and interact across the landscapes in which MOG is or could be located.

To better understand these stressors and drivers as interacting factors in an ecosystem, the Terrestrial Condition Assessment (TCA) was adapted to understand the ecological condition and potential threats to MOG in an integrated way. The TCA was developed by the Forest Service, and it leverages nationally consistent datasets to model ecological integrity on NFS lands at the mid-level (1:100,000) using land-type associations (LTA, units approximately 10,000 acres in size) or comparable spatial units representing ecosystems (Cleland et al. 2017, Nelson et al. 2015, Winthers et al. 2005). The TCA model is supported through the Ecosystem Management Decision Support (EMDS) logic model which provides transparency and repeatability for TCA while allowing TCA to incorporate information about the relationships between indicators and metrics of ecological integrity (Reynolds and Hessburg 2014). Since the TCA's initial development, it has been updated to better account for non-forested ecosystems on NFS lands (Anderson et al. 2020) and been leveraged to develop a key performance indicator (KPI) focused on ecological outcomes for the Forest Service (USDA Forest Service 2023).

The TCA provides one way to examine several stressors and drivers simultaneously and evaluate their collective impact. Additionally, the team that developed and maintains TCA has established processes to update the model annually to calculate and report the KPI. These methods could inform future efforts to revisit and reevaluate MOG conditions going forward. However, key differences exist between the goals and objectives of TCA and the goals and objectives laid out in E.O. 14072, Secretary's Memo 1077-004, and subsequent decisions made during the inventory of MOG:

- Time frame: The TCA models current ecological conditions. Current conditions are informed by historical trends and patterns which can identify important deviations and changes. The TCA leverages historical trends when assessing current conditions but does not make projections about future conditions. There is a distinct need to consider future conditions and future threats to MOG to identify appropriate courses of action that can mitigate potential threats.
- Spatial extent: The TCA was designed with explicit guidance to assess ecological conditions on NFS lands (Forest Service Correspondence 2012). The Executive order requires examining MOG across Federal lands which has been interpreted to define and inventory MOG for Forest Service and BLM lands.

- Analysis Scope: The TCA evaluates ecological conditions across all NFS lands which include several types of ecosystems from boreal and temperate forests to grasslands and shrublands. Physiognomic types other than forest are beyond the scope of the analysis of MOG; there is little need to examine MOG in places it does not and should not exist (e.g., grassland ecosystems).
- Analysis units: The TCA leverages LTAs where they have been mapped, and first approximations of LTAs have been modelled where LTAs are not yet available. LTAs are one level of the National Hierarchical Framework of Ecological Units (NHFEU, Winthers et al. 2005). The inventory of MOG was summarized to firesheds (which are units capturing fire risk to communities and exist outside of the NHFEU).

Based on the differences listed above, adaptations to TCA were needed to better align with the goals and objectives of the threat analysis. This led to the development of the Mature and Old-Growth Condition Assessment (MOGCA) which has key differences from the original TCA:

- Time frame: Once fully developed, MOGCA will examine both current and future conditions and threats to MOG.
- Spatial extent: The MOGCA will model ecological conditions of- and potential threats to-MOG on both NFS and BLM lands identified (at the fireshed scale) to contain MOG.
- Analysis scope: The MOGCA will focus on indicators and metrics germane to capturing potential threats to MOG and ecological conditions that could degrade MOG conditions. It will also focus only on forested areas, as defined by a forest mask layer, derived from remote sensing products.
- Analysis units: The MOGCA will be run using Project Areas which are polygons nested within firesheds. Project Areas average about 25,000 acres and range in size from approximately 9,000 to 38,000 acres, making them comparable in scale to LTAs.

The initial version of MOGCA focuses on current conditions and threats with the portion of the model devoted to future threats to be developed later. Additionally, there is potential to develop decision-support models within the EMDS framework for MOGCA to integrate information related to social, economic, and cultural values ascribed to MOG in different systems as that information becomes available.

The architecture of the model consists of a network of logic networks, in which each logic network evaluates evidence for a proposition (e.g., threat is absent) in terms of two or more logical premises or parameters (values/thresholds that define a condition, table A5.1). Each path through the logic architecture terminates in a data input that is interpreted based on the premises/parameters, and subsequently synthesized with the other data inputs for each Project Area. The model is data driven with higher level outcomes being evidence based and derived from the outcomes of the logic networks of the metrics and indicators directly tied to the data.

Table of Parameters and Thresholds

Parameters (often referred to as thresholds) used in the MOGCA model to define scores of -1 indicating Very Poor conditions or Very High threats (depending on the indicator) and scores of +1 indicating Very Good conditions or Very Low threats (depending on indicator, table A5.1).

Table A5.1.—Parameters used in the Mature and Old Growth Condition Assessment.

Indicator	Metrics	Parameter for −1	Parameter for +1	Summary Unit
Tree mortality	Tree mortality – most recent 5 years (2021 to 2017)	50	25	% area
	Tree mortality – previous 5 years (2016 to 2012)	50	25	% area
Uncharacteristic disturbance events	Uncharacteristically severe fire: low severity ecosystems	20	0	% area
	Uncharacteristically severe fire: moderate severity ecosystems	10	0	% area
Climate exposure	Spring temperature	2.5	0	°F changed
	Summer temperature	2.5	0	°F changed
	Fall temperature	2.5	0	°F changed
	Winter temperature	2.5	0	°F changed
	Spring precipitation (amount)	−1.0	0.0	inches
	Summer precipitation (amount)	−1.0	0.0	inches
	Fall precipitation (amount)	−1.0	0.0	inches
	Winter precipitation (amount)	−1.0	0.0	inches
	Spring precipitation (% change)	−10.0	0.0	% changed

Indicator	Metrics	Parameter for −1	Parameter for +1	Summary Unit
	Summer precipitation (% change)	−10.0	0.0	% changed
	Fall precipitation (% change)	−10.0	0.0	% changed
	Winter precipitation (% change)	−10.0	0.0	% changed
	Drought	−1.5	0.0	z-score difference
Road density	Paved roads	0.3	0.1	Miles per square mile
	Light duty roads	2.0	1.0	Miles per square mile
	Unimproved roads	2.5	1.0	Miles per square mile
Vegetation successional departure	Vegetation departure index	75	34	Index value
Air pollution	Nitrogen (N) deposition	Ecosystem dependent		Kilograms per hectare per year
Wildfire Threat to Late Seral	Cumulative expected Net Value Change (eNVC) due to wildfire	30	1	Percent of cumulative eNVC
Forest insect and disease hazard	Potential uncharacteristic mortality from insects and disease	35	5	% area
Ecological process departure	Fire deficit	95	33	% area

The goal of MOGCA is to examine the ecological conditions and potential threats to MOG. Thus, the highest-level in the network of logic networks is Overall MOG Condition which is determined for each Project Area by making logical inferences considering:

- Current condition,
- Current threats, and
- Future threats (to be developed).

Where TCA evaluates ecological integrity (Overall Terrestrial Condition) as the absence of ecological stressors, the MOGCA model evaluates the overall MOG condition as the absence of detrimental conditions and potential threats. Along these lines, the overall MOG condition can be thought of as an inference about MOG integrity. Several stressors and drivers are relevant to understanding both ecological integrity and threats to ecosystems. Thus, the initial version of MOGCA model is leveraging indicators and metrics from the TCA because the datasets and data summaries have already been reviewed, validated, and refined at a comparable scale by subject matter experts in consultation with the TCA team (table A5.2). In the future, these different indicators will be revisited with a greater focus on mature and old growth forest to improve the alignment of metrics with factors and measures most relevant to mature and old growth conditions and functions to manage and mitigate potential loss and/or degradation. For the initial threat analysis, several metrics and supporting datasets have been identified and incorporated into spatial overlays. Time constraints, however, did not allow for development, review, and evaluation of the parameters and model logic necessary for including these alternative metrics and data into MOGCA at this stage. The next MOGCA iteration will include these subject-matter expert identified datasets and metrics.

Table of Model Data Sources

Indicators and metrics included in the MOGCA to assess conditions of areas with MOG which makes an assessment of the ecological integrity of these areas. All except the Wildfire Threat to Late Seral was adapted from TCA.

Table A5.2.—Indicators and metrics used in the Mature and Old Growth Condition Assessment and associated data sources.

Indicator	Metrics	Data source
Current Conditions		
Recent Disturbances		
Tree mortality	Tree mortality – most recent 5 years (2021 to 2017) Tree mortality – previous 5 years (2016 to 2012)	FS FHAAST National Forest Pest Conditions Database
Uncharacteristic disturbance events	Uncharacteristically severe fire: low severity ecosystems	MTBS (fire severity data) and LF BPS (expected fire severity)

Indicator	Metrics	Data source
	Uncharacteristically severe fire: moderate severity ecosystems	
Stressors and Characteristics of Vegetation		
Climate exposure	Spring temperature	**P**arameter elevation **R**egression on **I**ndependent **S**lopes **M**odel (PRISM) Climate Group at Oregon State University
	Summer temperature	
	Fall temperature	
	Winter temperature	
	Spring precipitation (amount)	
	Summer precipitation (amount)	
	Fall precipitation (amount)	
	Winter precipitation (amount)	
	Spring precipitation (% change)	
	Summer precipitation (% change)	
	Fall precipitation (% change)	
	Winter precipitation (% change)	
	Drought	FS Office of Sustainability and Climate
Road density	Paved roads	USGS National Transportation Dataset
	Light duty roads	
	Unimproved roads	
Vegetation successional departure	Vegetation departure index	LF BPS models and succession class data using approach in Swaty et al. 2021
Air pollution	Nitrogen (N) deposition	NADP TDep Measurement-Model Fusion data

Current Threats

Indicator	Metrics	Data source
Wildfire Threat to Late Seral*	Cumulative expected Net Value Change (eNVC) due to wildfire	Quantitative wildfire risk assessment framework using LF BPS and succession class data and response functions by FS Fire Modeling Institute
Forest insect and disease hazard	Potential for uncharacteristic mortality from insects and disease	NIDRM produced by FS FHAAST
Ecological process departure	Fire deficit	LF MFRI (expected) and historical fire records (observed)

FS = Forest Service
FHAAST = Forest Health Assessment and Applied Sciences Team
USGS = United States Geological Survey
NADP = National Atmospheric Deposition Program
TDep = Total Deposition Science Committee
MTBS = Monitoring Trends in Burn Severity
LF = LANDFIRE https://landfire.gov/index.php
BPS = Biophysical Settings
NIDRM = National Insect and Disease Risk Map
MFRI = Mean Fire Return Interval
** = Denotes layer not used in TCA*

Six indicators capturing recent disturbances and other characteristics of/stressors to forests describe the Current Condition in MOGCA:

- The ***Recent Disturbances*** (disturbance agents) logic network is composed of two indicators:
    - **Tree Mortality** describes recent tree mortality caused by various insect outbreaks and pathogens as recorded by the aerial detection surveys. Data are from the US Forest Service Forest Health Assessment and Applied Sciences Team (FHAAST) National Forest Pest Conditions Database. Two metrics characterize recent mortality events (within the last 0–5 years, 2017–2021) and mortality events that have had some time to begin recovering (i.e., occurred within 6–10 years ago, 2016–2012).
    - **Uncharacteristic Wildfire** identifies areas that experienced unnaturally severe wildfires. It leverages information from the Biophysical Settings (BpS) from LANDFIRE to determine expected burn severities depending on the type of ecosystem and compares that to observed burn severities as recorded in the Monitoring Trends in Burn Severity (MTBS) data. One metric (Low Severity) identifies areas that have been mapped with a dominant condition of low severity fire but had a moderate or high severity MTBS fire pixel in that location. Another metric (Moderate Severity) identifies areas mapped with a dominant condition of mixed-severity fire and had a high severity MTBS fire pixel in that location.

- ***Vegetation Condition*** is composed of four indicators and captures other stressors and characteristics that have the potential to degrade ecological conditions or exacerbate other stressors and disturbances:
    - **Climate** examines how much current climatic conditions (drought, temperature, and precipitation) deviate from historical norms using data from the PRISM Climate Group. For seasonal temperature and precipitation, the average of the most-recent 5 years (2021–2017) is compared to the historical record going back to 1900 (2016–1900) to understand how much warmer and drier recent climate is. Drought measures moisture deficit as a z-score over the previous 3 years (2021–2019) compared to the historical record back to 1900.
    - **Road Density** looks at the miles per square mile of three different road types with varying levels of infrastructure, development, and use: paved roads (controlled access highways, secondary highways, major connecting roads, and ramps), light duty roads (local roads and local connecting roads), and unimproved roads (four-wheel drive roads). The USGS National Transportation Datasets vector dataset of national roads is used.
    - **Vegetation Departure** is an adaptation of LANDFIRE's Vegetation Departure Index based on methods described in Swaty et al. 2021. It leverages LANDFIRE's BpS dataset to identify an expected distribution of successional classes for the analysis area of interest and compares it to the observed distribution of successional classes in that area as described in LANDFIRE's S-class dataset.
    - **Air Pollution** examines levels of nitrogen deposition from the Total Deposition product from EPA and the National Atmospheric Deposition Program (NADP). It determines where exceedances are occurring based on ecosystem-dependent critical loads documented in the National Critical Loads Database (NCLD).
    - **Terrestrial Invasive Species** are recognized as an important stressor on ecosystems that impair and deteriorate ecological conditions with the potential to degrade key characteristics of MOG. However, nationally consistent data are not available at the scale of Project Areas. Nationally consistent data are mostly available at the fireshed level; however, more time is needed to interpret this data in regard to mature and old growth forest conditions.

Recognizing when a stressor or disturbance has the potential to become a threat to mature and old growth forest is an ecosystem and location dependent determination. Certain stressors and drivers are more readily characterized in the ways that they threaten either MOG forests specifically and/or forests more broadly. Although many potential threats have been identified, three have been characterized thus far with nationally consistent data to form the basis for three indicators of current threats to MOG and/or the ecosystems in which MOG resides:

- **Wildfire Threat to Late Seral Forests** is focused on where the probability is high that wildfires would result in the loss of late seral forests. A geospatial layer was specifically developed to consider this threat using a standard quantitative wildfire risk assessment

(QWRA) framework that considered both annual burn probability (BP) and the conditional Net Value Change (cNVC) to determine the expected Net Value Change (eNVC). The cNVC leverages a series of response functions that quantify the degree of loss across six fire intensity levels based on flame lengths. LANDFIRE successional class (SClass) data were used to identify areas with late seral forests, as a proxy for MOG because it was spatially explicit at an appropriate scale for this analysis.

- **Forest Insect and Disease Hazard** identifies areas with unhealthy forest conditions based on a combination of stand and environmental characteristics making them uncharacteristically vulnerable to insect and disease outbreaks. This indicator uses the National Insect and Disease Risk Map (NIDRM) from FHAAST.
- **Fire Deficit** identifies areas burning less frequently than they did under natural disturbance regimes. Often, these missed fire cycles were due to human factors, principally fire suppression since the beginning of the 20th century. The historic mean fire return interval (MFRI) from LANDFIRE BpS is used to determine fire frequency of the natural fire regime, and it is compared to observed frequency of fire from historical fire records extending back to the 1920s.

The Future Threats component of the MOGCA model will be developed leveraging data from various scenarios and projections of future conditions identified during this initial analysis of potential threats to MOG. During this initial analysis, several groups of subject matter experts have identified different data layers regarding future conditions that inform how to understand projected trends in key climate variables (such as heat or drought) and wildfire.

Both Current Condition and Current Threat (and Future Threat, once developed) along with each indicator has its own logic network. The evaluated state of each logic network (i.e., the outcomes for each Project Area) can be displayed as a map in the EMDS application for MOG threat. The user can display as few or as many of the networks as they wish. Although EMDS output is continuous, it is easier to visualize classes, and generally the results were classified into five classes of very low (dark brown) to very high (dark green) evidence. Basing map symbology for evidence can be somewhat confusing in the MOG threat analysis context, in which we are evaluating evidence for absence of threat. This translates into very high evidence (represented by dark green) equating to very good ecological conditions and/or very low threat; conversely, very low evidence (represented by dark brown) equates to very poor ecological conditions and/or very high threat.

To better understand threats to MOG and focus the analysis, a federal forest mask was developed for summarizing datasets with finer spatial resolution (<4km). The goal was to focus on the same areas targeted in the inventory (i.e., Forest Service and BLM lands); this was identified using the basic ownership data layer filtered to areas owned by the Forest Service and BLM. Because the MOG inventory is reliable to the scale of firesheds, which are coarser than the MOGCA model (i.e., the scale of Project Areas) and many of the input datasets (raster layers with resolution as fine as 30 meters), a mask was developed to focus the analysis on areas that are forested. Based on prior work examining forest landcover layers for another application (Patterson et al. 2022), the Landscape Change Monitoring System (LCMS, Housman et al. 2022) forested land cover

layer was selected with a 30-percent probability threshold. The LCMS forested land cover layer makes use of the full LANDSAT record to identify the probability that a given pixel could be forested. The 30-percent threshold allows for areas that have had recent tree removal from human (e.g., harvest or stand improvement work) or natural (e.g., wildfire) to still be recognized as forested.

The inventory identified approximately 2,500 firesheds that contain mature and/or old growth forest. Those firesheds are composed of nearly 21,000 Project Areas, but not all those Project Areas contain forested, federally owned land. Thus, a threshold of 10 percent forested-federally owned land was implemented to identify which Project Areas to include in the analysis carried out by MOGCA model. This removed nearly 9,000 Project Areas from the analysis, reducing the number analyzed down to 11,779 Project Areas across the conterminous United States included in the modeling, which represent an area of nearly 300 million acres of land of which 76.1 percent is forested, and 55.2 percent of it is both forested and federally owned. The 165 million acres of federally forested land analyzed includes areas of young, mature, and old-growth forest.

Future Work and Model Improvements

The Mature and Old Growth Condition Assessment (MOGCA) model is a proof of concept demonstrating the importance of considering multiple potential threats and factors that can degrade the ecological condition of MOG simultaneously. Stressors and drivers often interact with compounding effects. Examining multiple stressors and drivers simultaneously sparks questions and forces considerations that are unlikely to be made when considering factors individually. It also invites comparisons while acknowledging differences across ecosystems, forest types, and regions (both ecological and administrative).

The current version of MOGCA was developed on an extremely tight timeline. The original vision was to address both current and future conditions and potential threats and to incorporate data sources, metrics, and variables garnered from subject matter experts based on threats identified through other parts of the threat analysis and public engagement sessions. Time constraints limited progress to only identifying the key datasets and variables with subject matter experts which led to their inclusion in the spatial overlay analyses. Additional review and evaluation are necessary to determine how best to summarize these datasets to the Project Areas and to set meaningful thresholds for inclusions of these variables in the MOGCA.

Some of the datasets borrowed from the TCA are the same ones recommended by the subject matter experts consulted in the development of MOGCA. Even these datasets would benefit from further evaluation and review. Initial subject matter expert review identified key places where thresholds and result summaries could be further refined to better capture potential threats and conditions that could degrade MOG. One example of this is the thresholds used with the Insect and Disease Hazard measure which is based on the NIDRM. Initially, the data summary (percent area identified to have risk, defined as projected basal area loss greater than 25 percent caused by insects and disease over the next 15 years) was using the same thresholds as TCA (figure A5.1). Upon review with the subject matter experts, the results layer of scores was found to be missing key areas with some remaining risk following prior insect and disease outbreaks and wildfire.

With further investigation, it was clear that applying the mask of federally owned forested lands to layers removed unforested areas from the data summary unit (percent area of the Project Area) and focused the analysis on forests. The TCA is examining the whole ecosystem, including non-forested areas, which made larger thresholds more appropriate to account for areas that are not forested. In MOGCA, the masking to forested areas focuses the analysis which causes a need for lower thresholds to detect the same inputs. Refining thresholds is a process, and different objectives can favor one alternative over another. For example, recommended thresholds have been identified that help capture areas known with risk and distinguish more across areas with different levels of risk (figure A5.2a). An alternative could be to really highlight risk which could be done by setting thresholds even lower than the recommended, which causes more areas to have low scores indicating poorer ecological conditions and higher levels of potential threat (figure A5.2b).

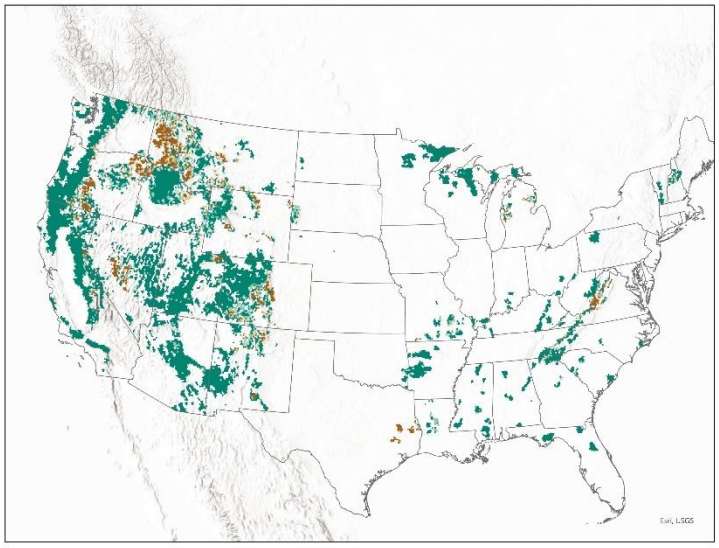
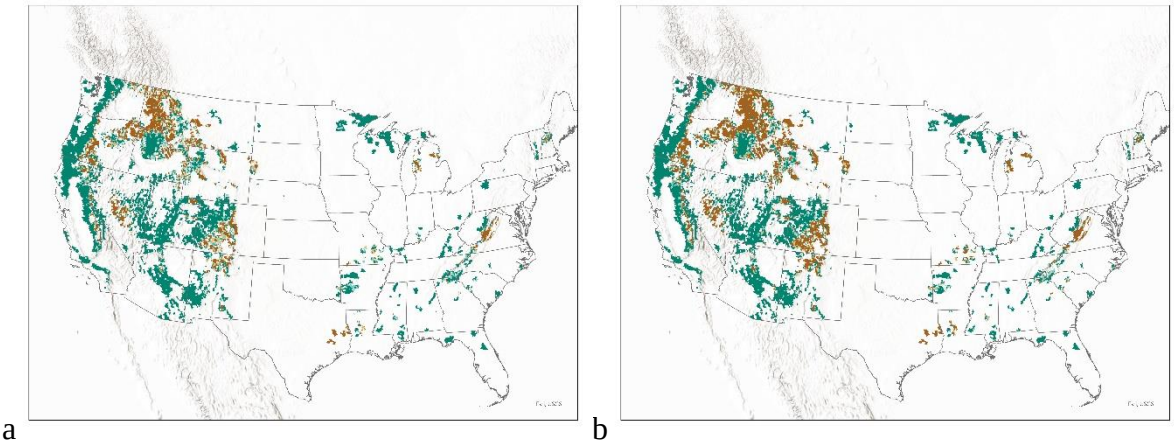


Figure A5.1.— Map of the results generated using the initial thresholds for Insect and Disease Hazard (50% for −1 and 10% for +1). The indicator is based on data from the National Insect and Disease Risk Map. Scores are continuous, and quantiles of the continuous scores are used to create condition classes ranging from Very High (scores >=−1 and <−0.6) to Very Low (scores =<+1.0 and >+0.6) threat.



a b

Figure A5.2.— Different thresholds were evaluated by subject matter experts to determine the most appropriate thresholds to discern levels of threat posed by insect and disease outbreaks as depicted by the National Insect and Disease Risk Map. The thresholds recommended by subject matter experts and ultimately used by MOGCA were 35% of the analysis unit area as a threshold for −1 and 5% of the analysis unit area as a threshold for +1 (A5.2a). Other thresholds were tested including thresholds of 25% for a score of −1 and 5% for a score of +1 that highlight areas threatened but discern less across different amounts of area at risk and under threat (A5.2b).

Results

Overall MOG Conditions and Potential Threats

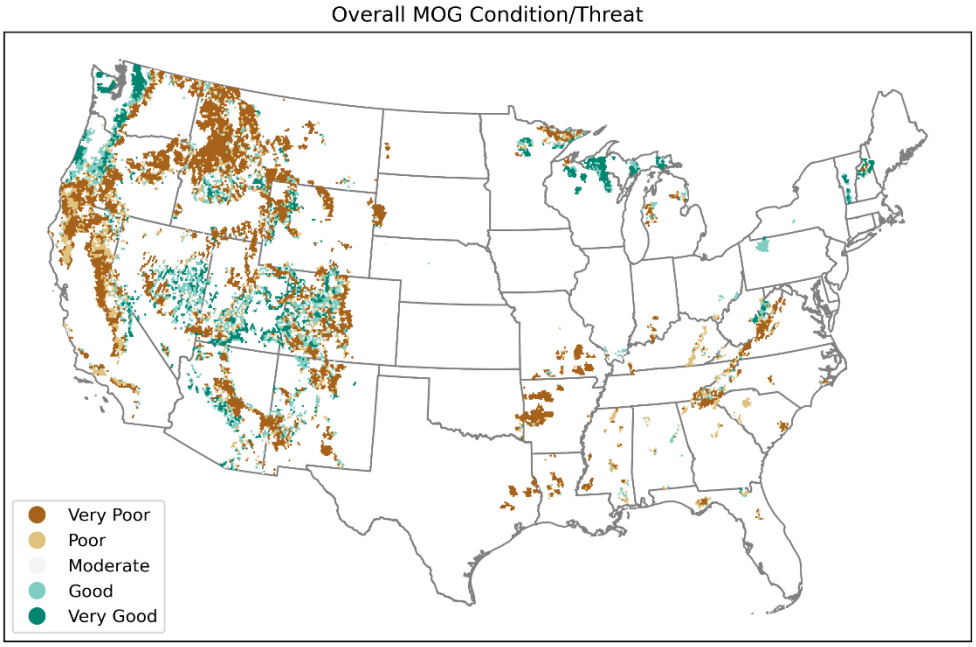


Figure A5.3.— Map of the overall MOG conditions which depicts an assessment of the overall current integrity of Project Areas with MOG across Forest Service and Bureau of Land Management lands. Overall MOG Conditions are derived by the Mature and Old Growth Condition Assessment from a combination of current conditions and current threats.

The overall MOG condition (current condition + current threats) varies across the country (figure A5.3). Over 5,000 Project Areas representing just under half of the federally owned forested land

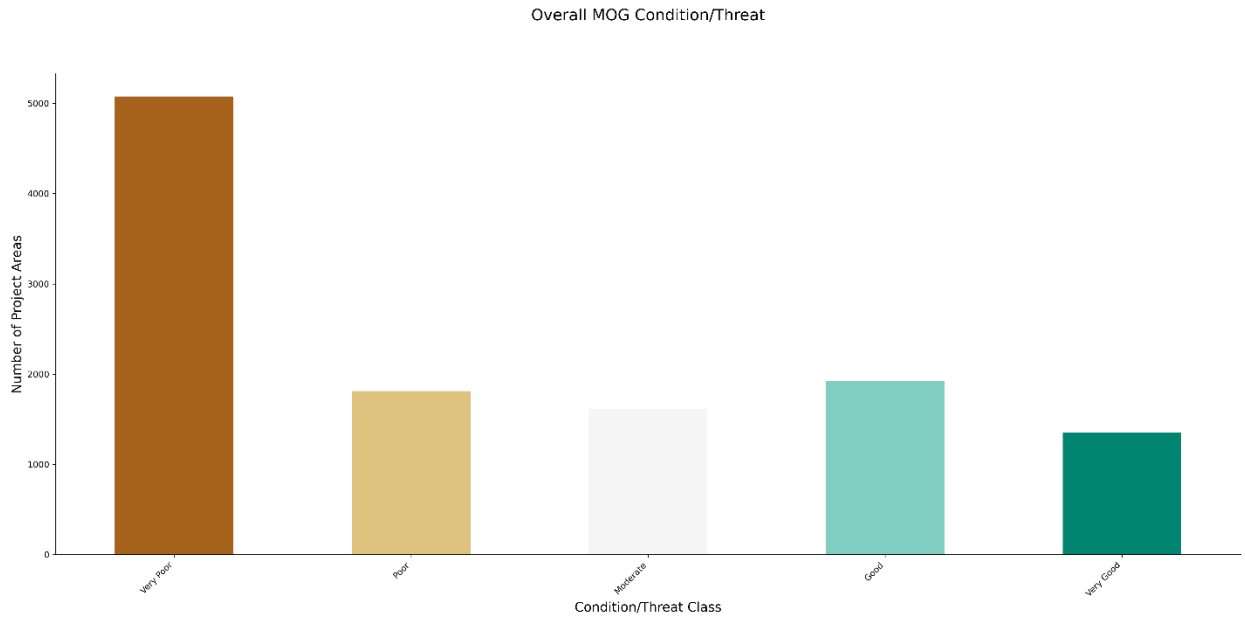
were rated as Very Poor for overall MOG condition (figure A5.4). The remaining four condition classes had a relatively even distribution of Project Areas (between 1,300 and 1,900) across the remaining four condition classes. Classes represent even divisions (ranges of 0.4) of the full range of possible model scores (very highest score = +1, very lowest score =−1); these are used consistently across indicators and metrics for visualization purposes of the continuous data (table A5.3).

Table A5.3.—Ranges of continuous scores used to define the condition and threat classes used to characterize output scores from the Mature and Old Growth Condition Assessment (MOGCA) model. Good (poor) ecological conditions are aligned with lower (higher) threats.

Condition Class	Threat Class	Range of Scores
Very Good	Very Low	+1.0 to +0.6
Good	Low	+0.6 to +0.2
Moderate	Moderate	+0.2 to −0.2
Poor	High	−0.2 to −0.6
Very Poor	Very High	−0.6 to −1.0

Overall MOG condition is driven more by Current Threats across the country than by Current Condition, except in the California mixed conifer forest type (much of California) where both Current Condition and Current Threats are contributing to overall poorer conditions and higher threats for MOG.

a



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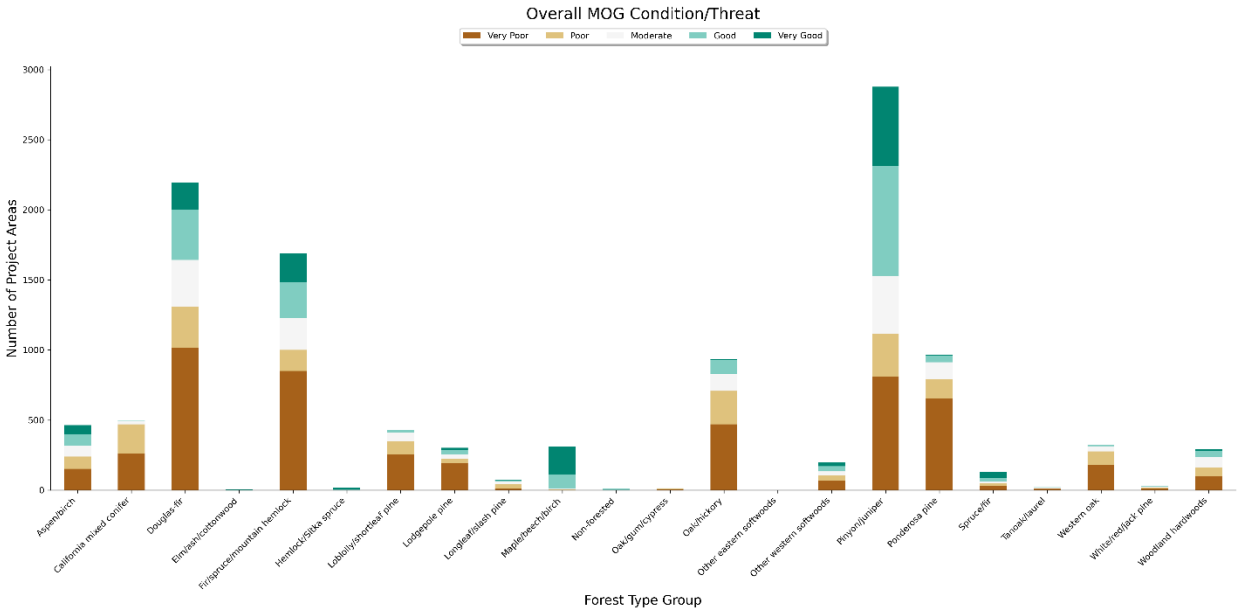

Figure A5.4.—The Overall Mature and Old Growth Condition from MOGCA depicted by the number of Project Areas by (A5.4a) condition class and by (A5.4b) forest type group. Nationally, 5,077 Project Areas were in Very Poor condition, 1,812 in Poor condition, 1,611 in Moderate condition, 1,923 in Good condition, and 1,356 in Very Good condition.

Current Condition

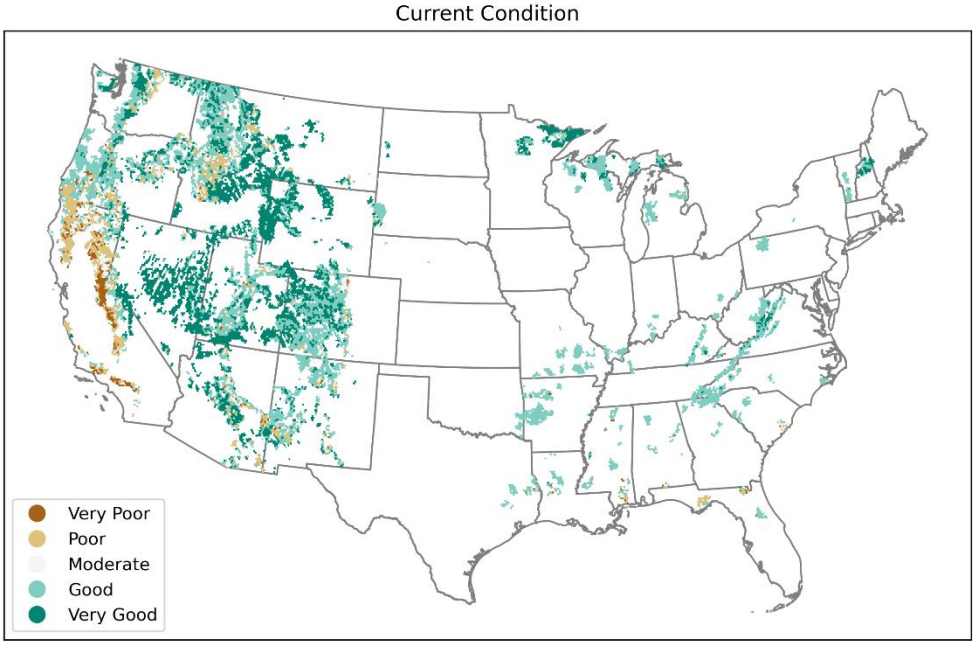

Figure A5.5.—The Current Condition of Project Areas containing federally owned forest land from the MOGCA model. Current Condition is determined by the outcomes of Recent Disturbances and Vegetation Condition which includes various stressors and characteristics of the current forest vegetation community.

Recent Disturbances

Tree Mortality from Insect and Disease Outbreaks

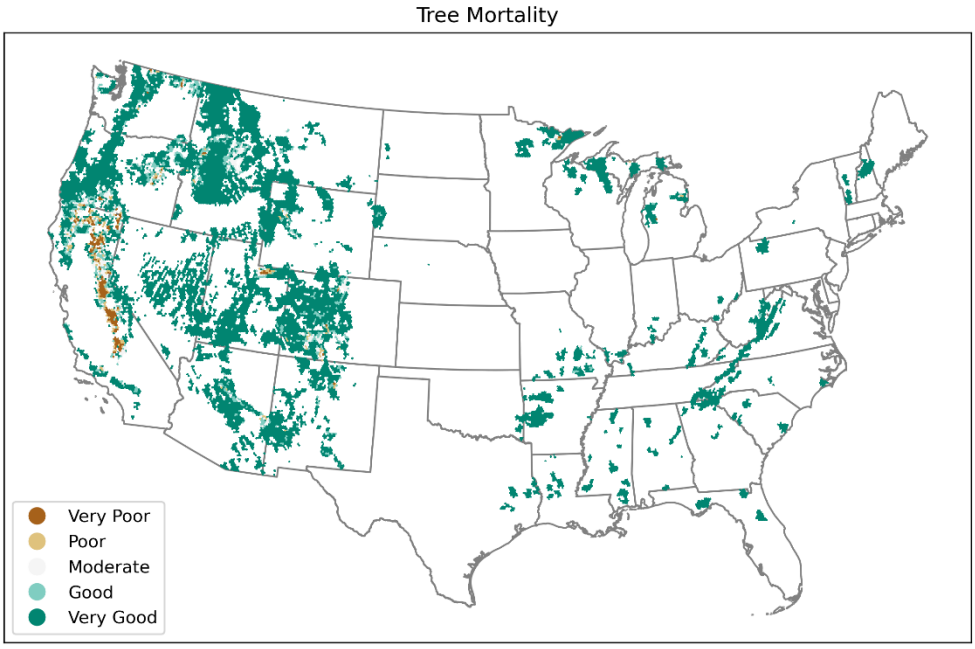

Figure A5.6.—Mapped condition classes of the Tree Mortality indicator for Project Areas containing federally owned forest land from the MOGCA model. The Tree Mortality indicator is composed of two metrics looking at extent of tree mortality documented in the most recent five years (2021-2017) and the five years preceding that period (2016-2012).

Although insect and disease events have occurred across the country over the last 10 years (figure A5.6), the outbreaks contributing to tree mortality events have been concentrated in the California mixed conifer forest type with some notable mortality occurring in the Fir, spruce, mountain hemlock forest type (figure A5.7b). In total, about 3 percent or 392 Project Areas had enough area experiencing tree mortality from insects and disease to be classified as Poor or Very Poor, and this represented just over 4 percent of the federally owned forested land considered in this analysis or about 6.7 million acres. This leads to more than 90 percent of Project Areas representing approximately 149 million acres of federally owned forested land having scores classified as Good and Very Good conditions where significant tree mortality was not observed during the two time periods analyzed.

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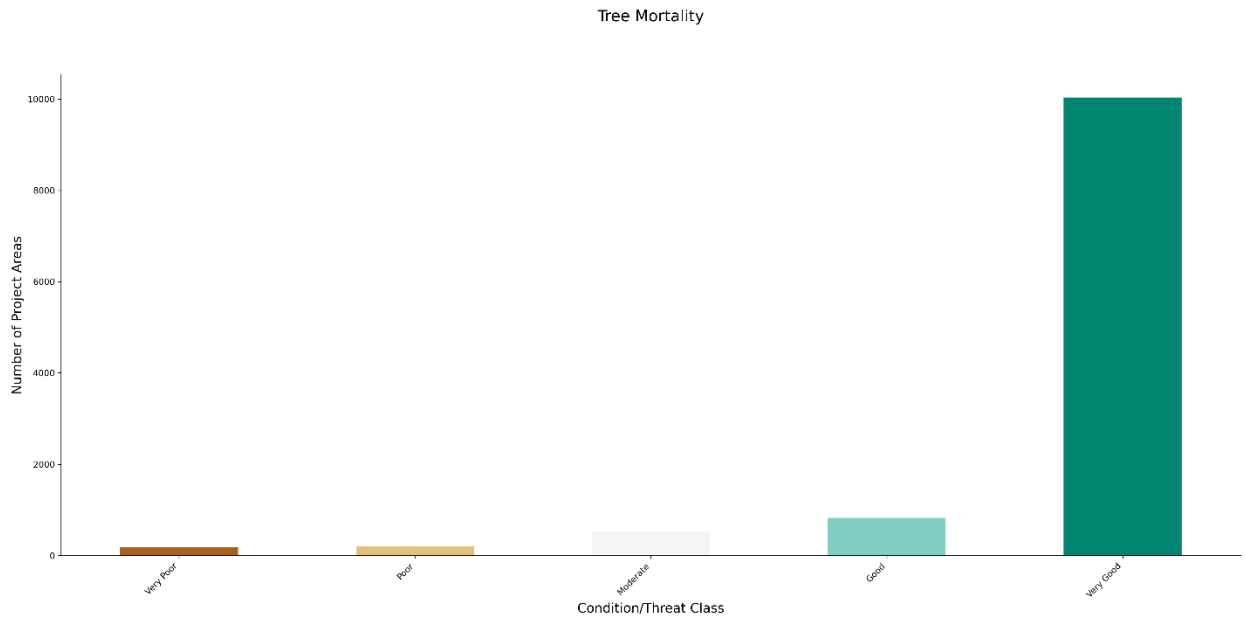

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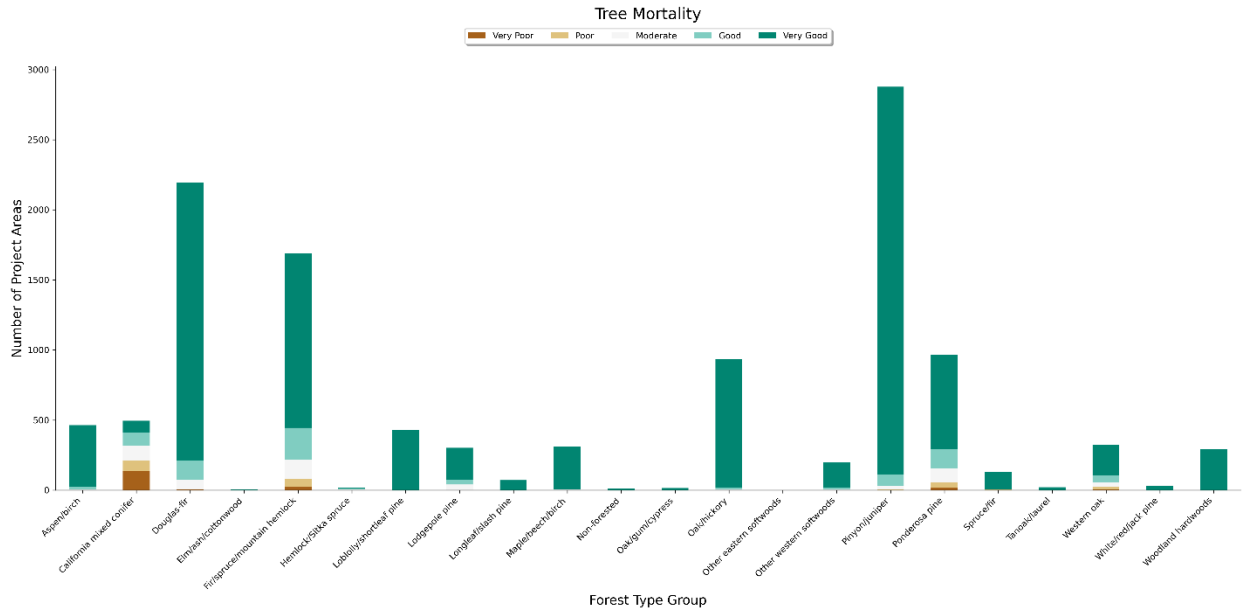


Figure A5.7.—The number of Project Areas by (A5.7a) condition class and by (A5.7b) forest type group for the Tree Mortality indicator. Nationally, 192 Project Areas were in Very Poor condition, 200 in Poor condition, 528 in Moderate condition, 824 in Good condition, and 10,035 in Very Good condition. Most Project Areas rated as in Poor or Very Poor conditions for this indicator occurred in the California mixed conifer forest type group.

Uncharacteristic Wildfires

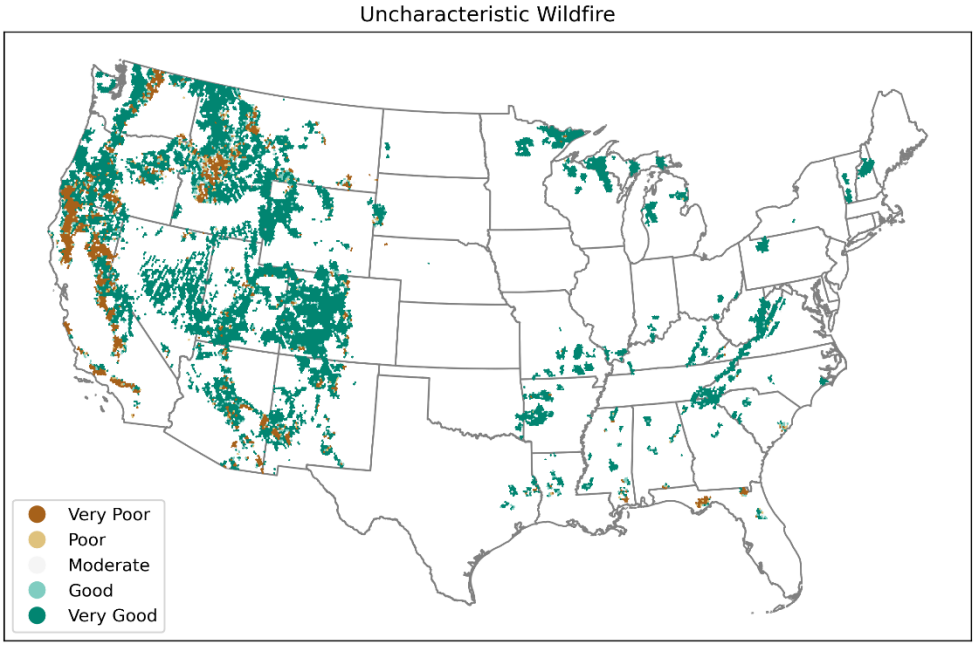
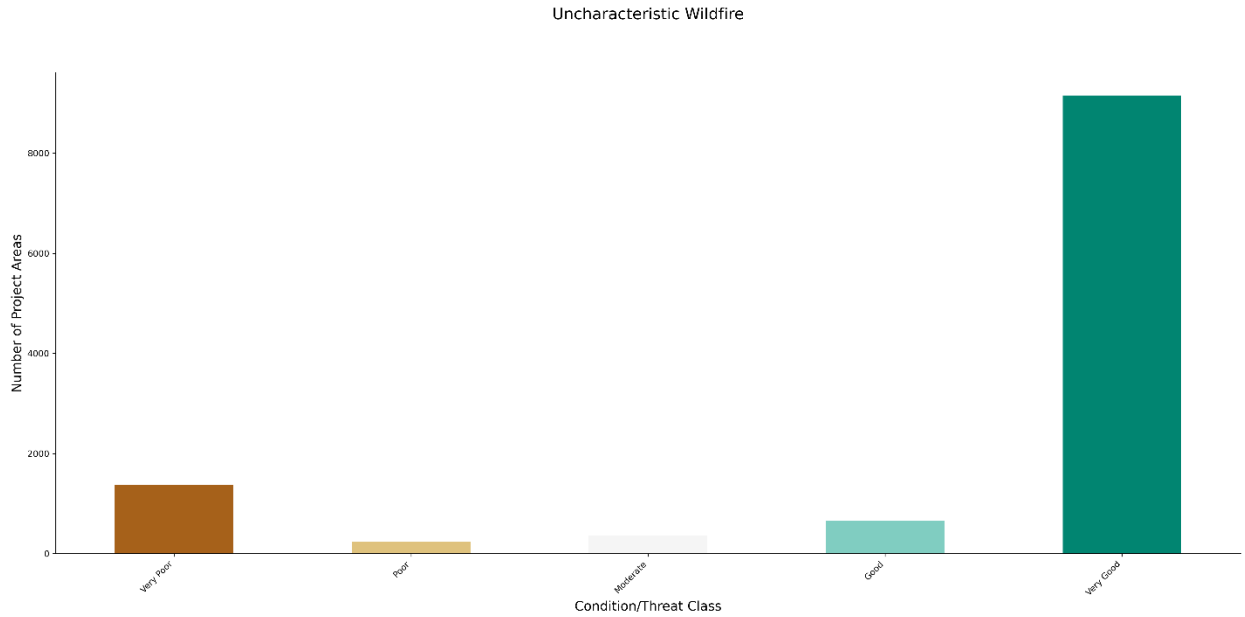


Figure A5.8.—Mapped condition classes of the Uncharacteristic Wildfire indicator for Project Areas containing federally owned forest land from the MOGCA model. The Uncharacteristic Wildfire indicator depicts where areas have burned more severely than expected based on the historical fire regime. It is composed of two metrics: one focused on areas with ecosystems characterized by low severity fire regimes that burned at higher severities and another on ecosystems characterized by moderate/mixed severity fire regimes that burned at high severities.

More Project Areas have experienced uncharacteristically severe wildfires than significant tree mortality from insects and disease with 1,609 Project Areas receiving scores rated as Poor and Very Poor conditions (figure 5.8, figure A5.9a); this represents over 28 million acres of federal forested lands. Lower scores indicate that more of the Project Areas have burned at a higher severity than expected for that ecosystem. Many Project Areas with uncharacteristically severe burned portions were dominated by the California mixed conifer forest type, although many Project Areas burned at uncharacteristically high severities occurred in the Western oak forest type (figure A5.9b). It is also worth noting the number of Project Areas with uncharacteristically severe fires in Project Areas dominated by Douglas fir, and Ponderosa pine forest types. These forest types that contain more uncharacteristically severe burned areas are occurring in western forest types.

a



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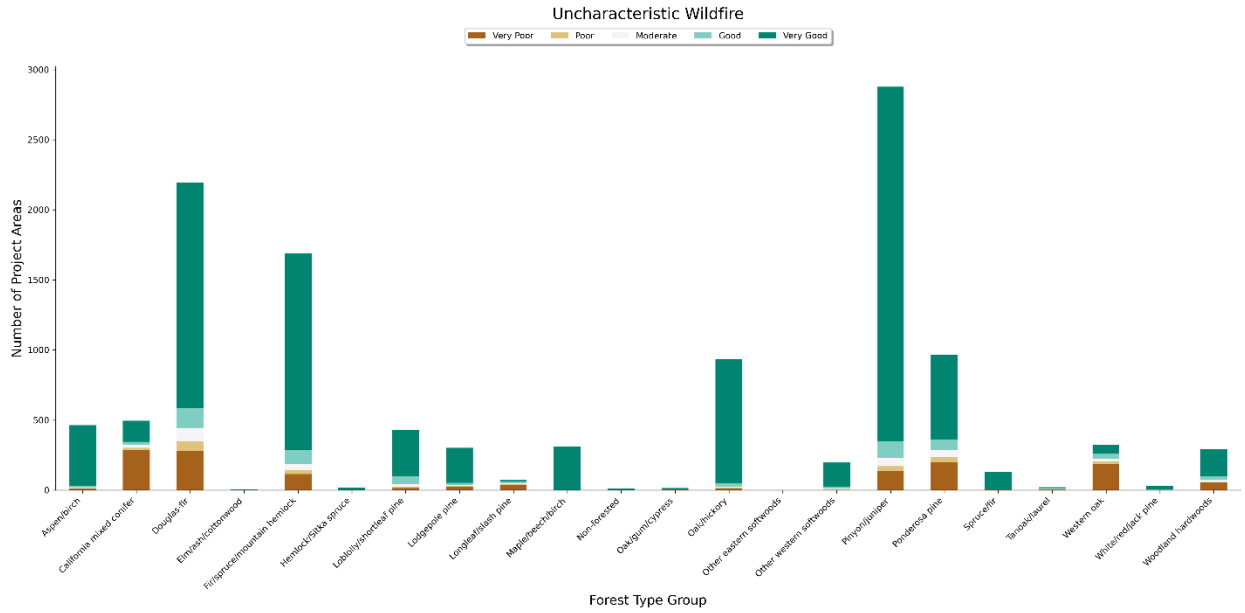

Figure A5.9.—The number of Project Areas by (A5.9a) condition class and by (A5.9b) forest type group for the Uncharacteristic Wildfire indicator. Nationally, 1,370 Project Areas were in Very Poor condition, 239 in Poor condition, 363 in Moderate condition, 652 in Good condition, and 9,155 in Very Good condition.

Stressors and Characteristics of Vegetation Conditions

Climate

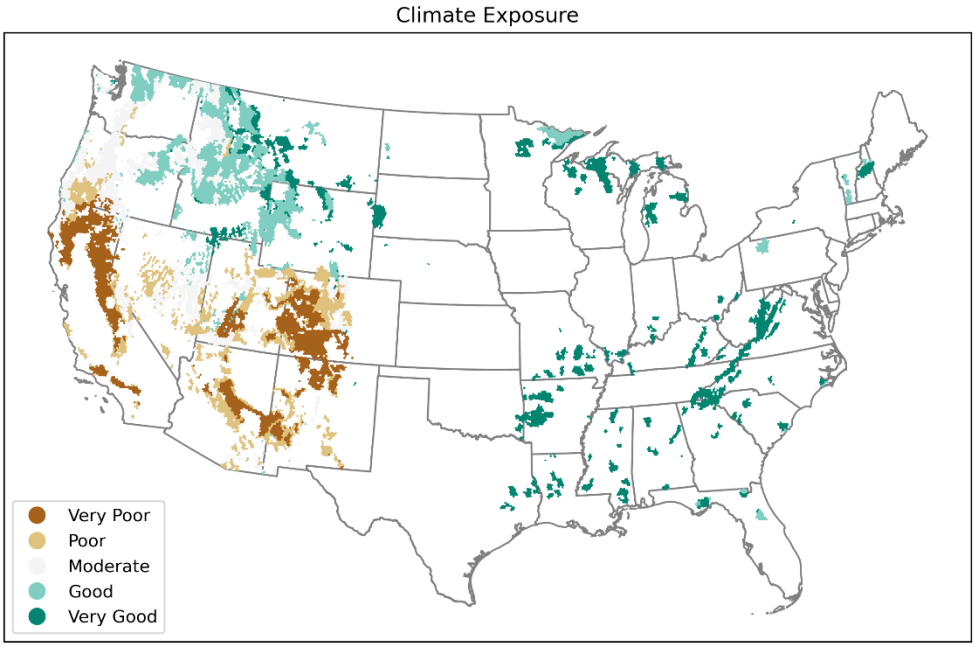

Figure A5.10.—Mapped condition classes of the Climate Exposure indicator for Project Areas containing federally owned forest land from the MOGCA model. The Climate Exposure indicator depicts how much recent climate conditions have deviated from the historical record. It considers metrics on seasonal temperature, seasonal precipitation, and drought.

Lower scores correspond to current climatic conditions (i.e., drought from 2021 to 2019 and seasonal temperatures and precipitation from 2021 to 2017) that are more departed from the historical baseline (climate records back to 1900), and the more departed values are interpreted to represent more stress and therefore poorer ecological conditions (figure A5.10). These more departed (with lower scores classified as poorer conditions) climate measures are concentrated in the southwestern portions of the United States with Project Areas dominated by the California mixed conifer, Pinyon-juniper, Tanoak-laurel, and Western oak forest types (figure A5.11). More Project Areas dominated by these forest types were classified as Poor or Very Poor than the other condition classes. These conditions correspond with Drought (figure A5.12) and Temperature measures (figure A5.13), especially spring, summer, and fall temperatures that are much warmer than the historical record. Warm winter temperatures have a different pattern with more eastern portions of the country showing departures from the historical record with more Poor and Very Poor ratings during this season compared to others for the Longleaf-slash pine, Maple-beech-birch, Oak-gum-cypress, and Oak-hickory forest types.

Seasonal precipitation measures indicate drier conditions are more prevalent in the West compared to the East over the recent past compared to the historical record as is indicated by lower scores representing the Poor and Very Poor condition classes (figure A5.14).

Summer conditions for both temperature (indicating warmer than the historical record) and precipitation (indicating drier than the historical record) have much more area in Very Poor

conditions (scores below -0.6) than the other seasons, and those areas are predominantly in the western United States.

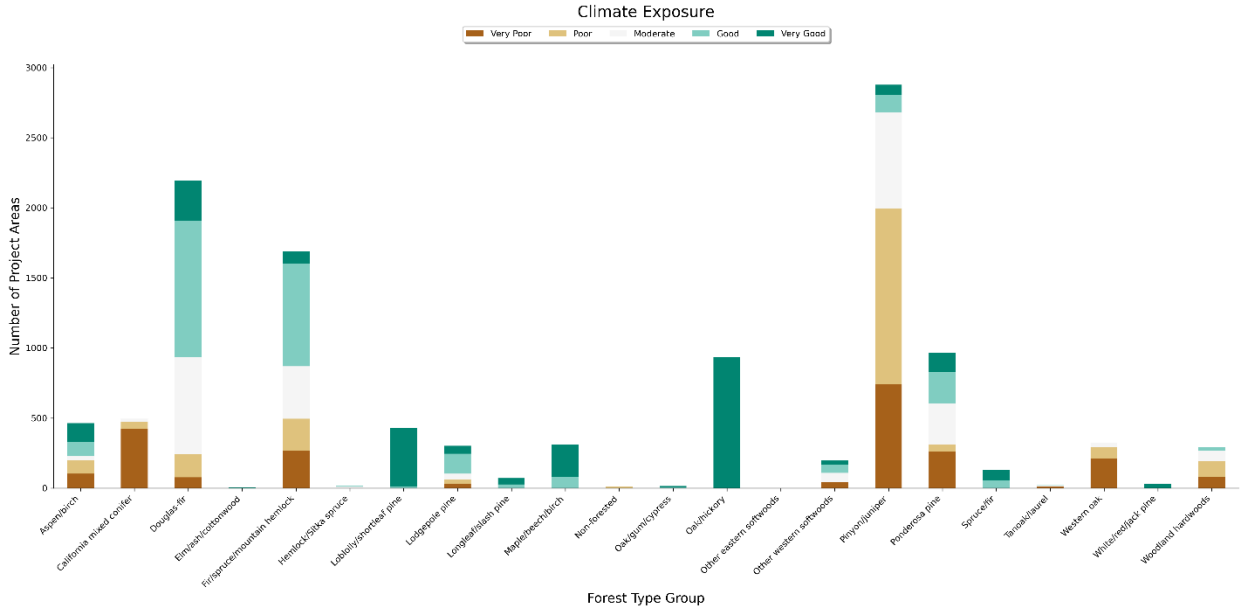

Figure A5.11.—The number of Project Areas by forest type group and condition class for the Climate Exposure indicator. Nationally, across all forest type groups, 2,247 Project Areas were in Very Poor condition, 2,081 in Poor condition, 2,336 in Moderate condition, 2,573 in Good condition, and 2,542 in Very Good condition.

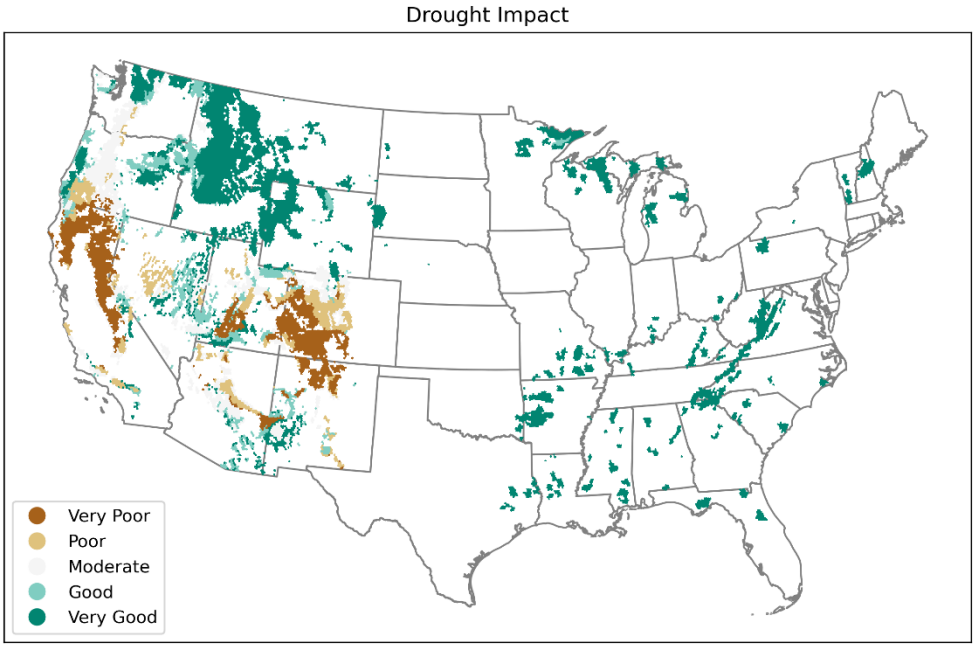

Figure A5.12.—Mapped condition classes of the Drought metric for Project Areas containing federally owned forest land from the MOGCA model. The Drought metric examines MDZ scores over the last three years (2021-2019) compared to the historical record. It is one of 13 metrics considered in the Climate Exposure indicator in the MOGCA model.

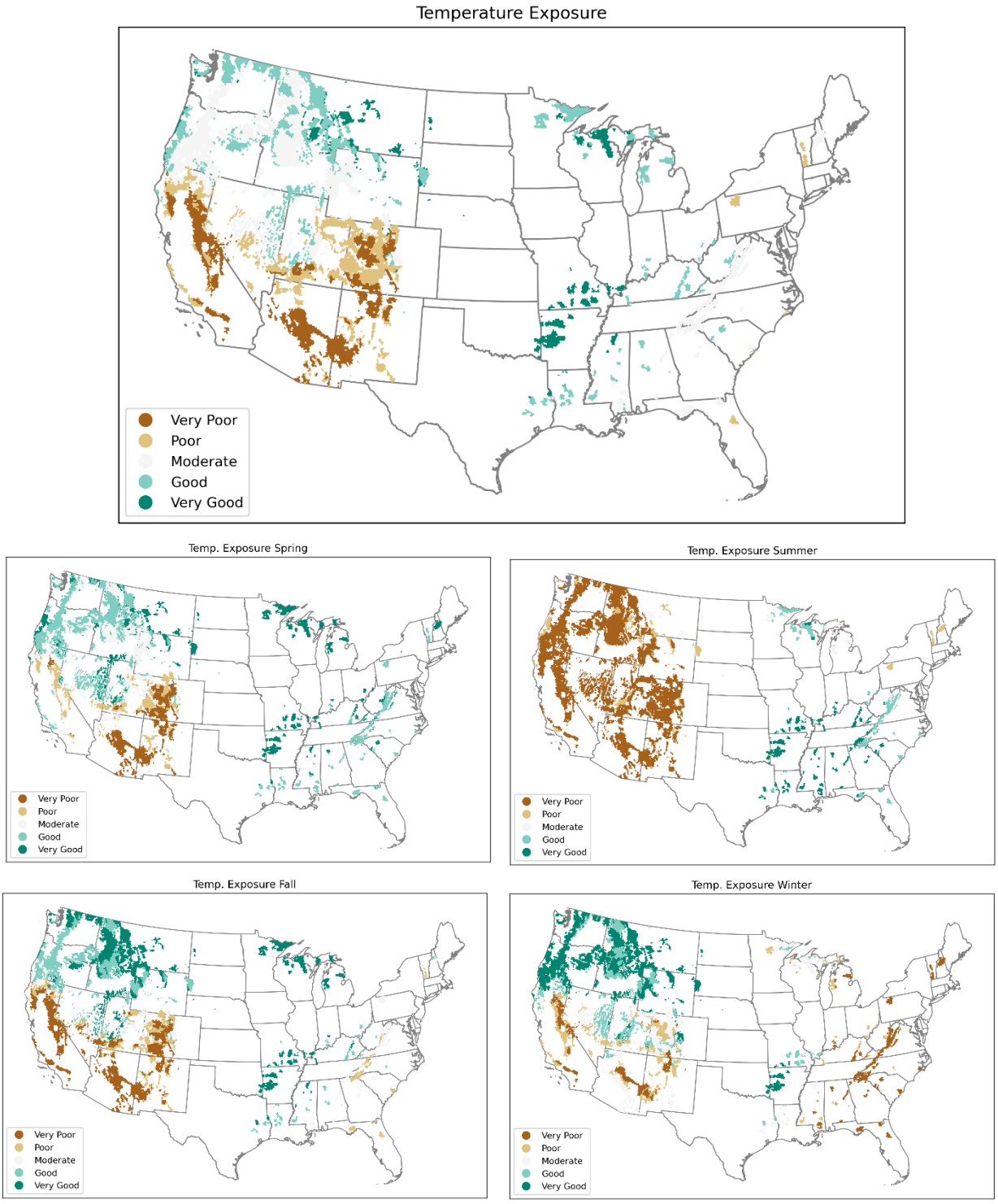

Figure A5.13.—Mapped condition classes of the Temperature Exposure metrics for Project Areas containing federally owned forest land from the MOGCA model. Temperature Exposure is generated from four seasonal measures (Spring, Summer, Fall, and Winter) that look at average seasonal temperatures over the most recent 5 years (2021-2017) compared to the historical record.

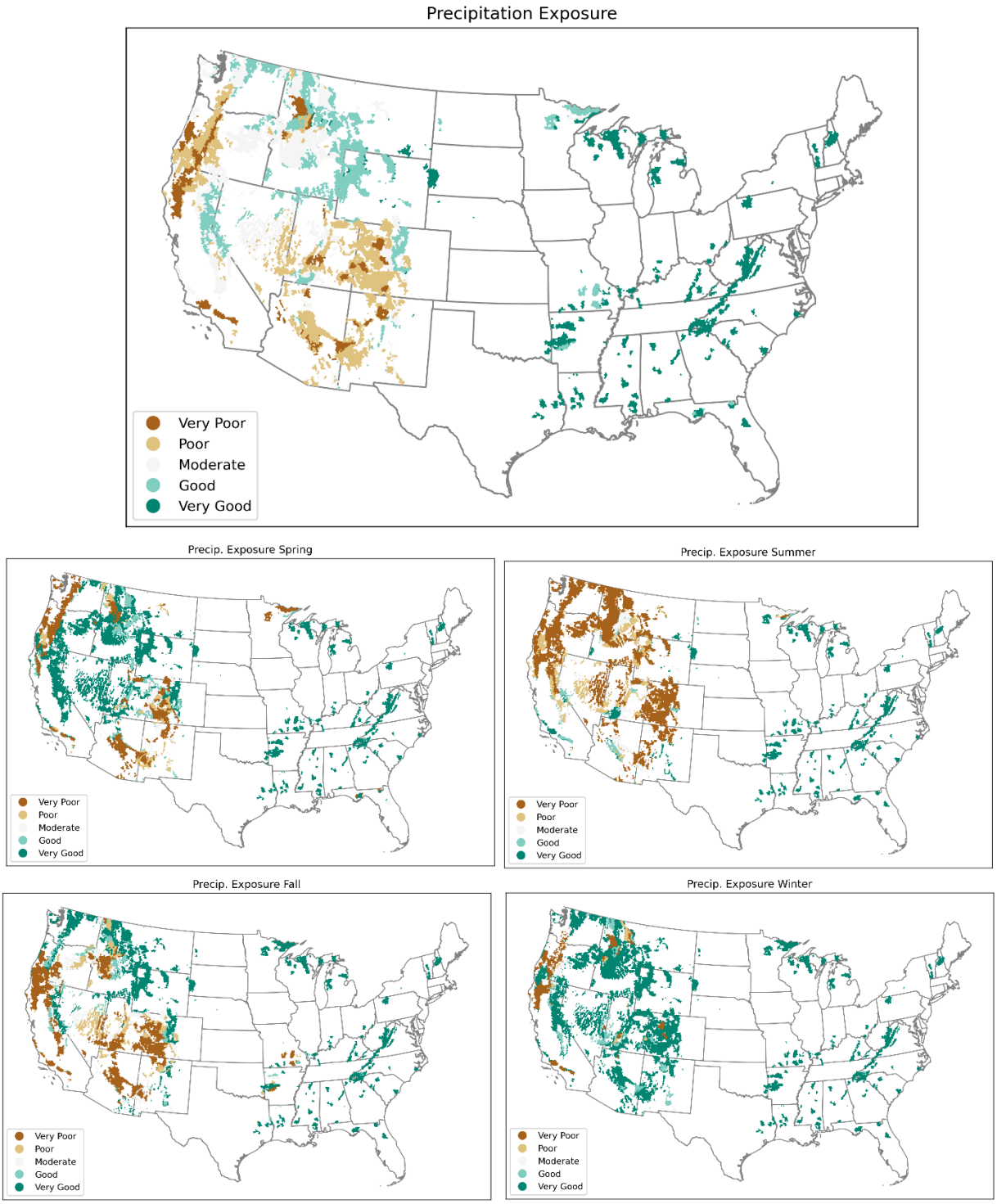

Figure A5.14.—Mapped condition classes of the Precipitation Exposure metrics for Project Areas containing federally owned forest land from the MOGCA model. Precipitation Exposure is generated from four seasonal measures (Spring, Summer, Fall, and Winter) that look at average seasonal precipitation amounts over the most recent 5 years (2021-2017) compared to the historical record.

Roads

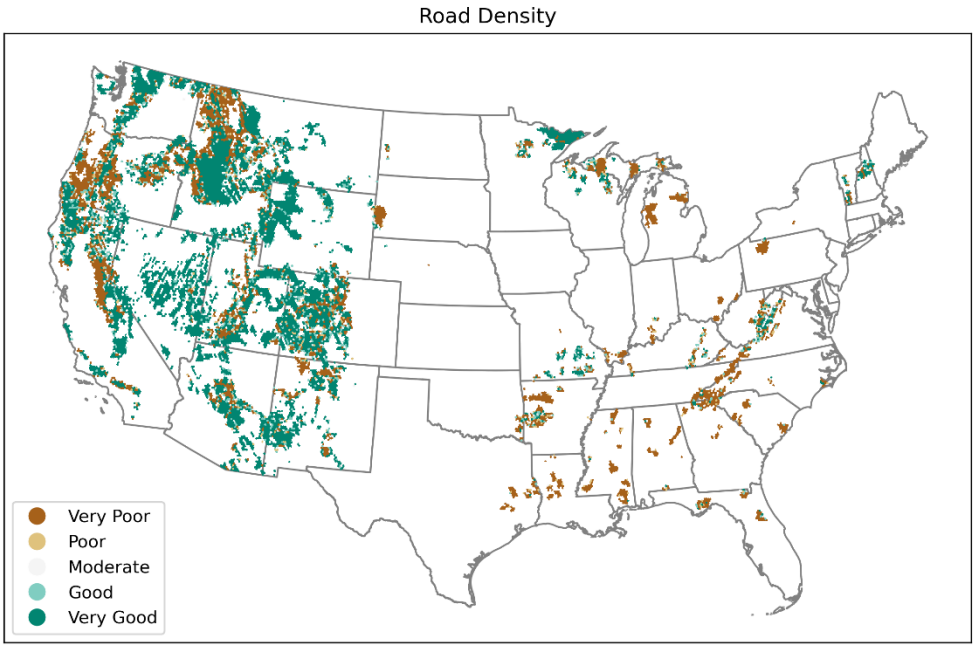

Figure A5.15.—Mapped condition classes of the Road indicator for Project Areas containing federally owned forest land from the MOGCA model. The Roads indicators is derived from three roads metrics that capture different road types that vary in their size and volume of traffic: paved roads, light duty roads, and unimproved roads. Roads negatively impact ecological conditions by fragmenting the landscape while also providing conduits for access which is necessary to enable restoration work.

Roads can fragment and break-up the continuity of ecosystems with numerous impacts to wildlife and ecosystem processes, most of which are adverse (Clifford 1959, Forman et al. 2003, Miller et al. 1996, Watkins et al. 2003). They provide conduits that increase the risk of fire starts and the spread of invasive species. They also can detract from characteristics perceived as important to MOG conditions such as solitude. Conversely, roads can be viewed positively from social and economic perspectives as they provide access for recreation and restoration work. Uniquely, they are an indicator that impacts most regions of the country (figure A5.15), indicated by Very Poor conditions occurring across most forest types (figure A5.16). Most notable is the Loblolly-shortleaf pine, Longleaf-slash pine, Oak-hickory, and White-red-jack pine forest types across the eastern US where the majority of Project Areas dominated by those forest type groups have scores below −0.6, indicating Very Poor conditions.

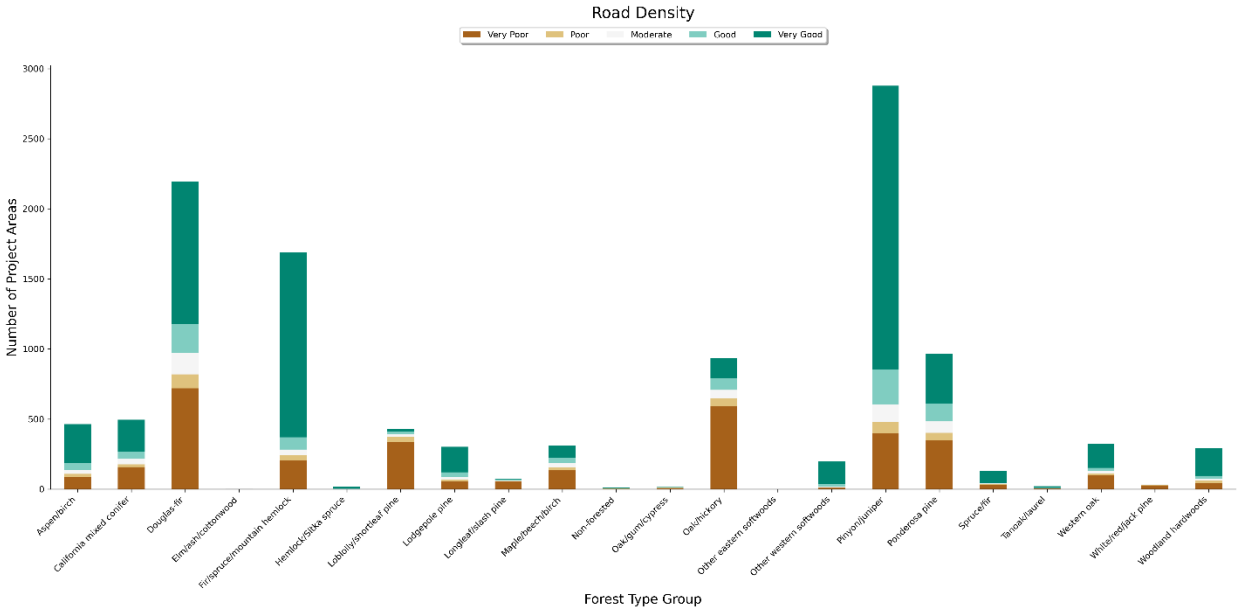

Figure A5.16.—The number of Project Areas by forest type group and condition class for the Road Density indicator. Nationally, 3,313 Project Areas were in Very Poor condition, 489 in Poor condition, 632 in Moderate condition, 1,024 in Good condition, and 6,321 in Very Good condition.

Vegetation Departure

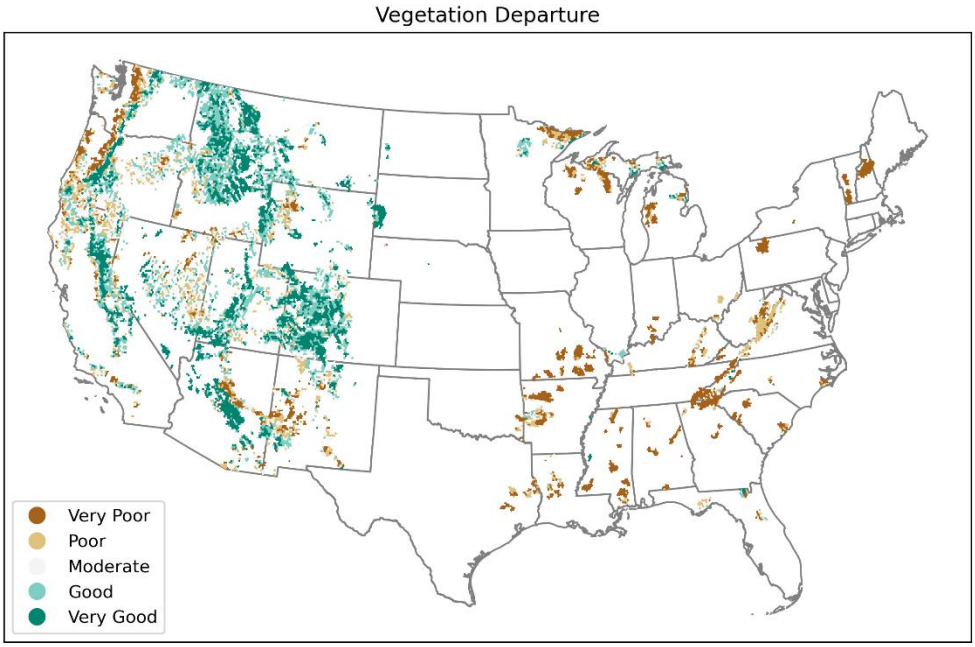

Figure A5.17.—Mapped condition classes of the Vegetation Departure indicator for Project Areas containing federally owned forest land from the MOGCA model. Vegetation Departure depicts the departure of the distribution of observed successional classes compared to the expected distribution for that ecosystem.

Vegetation Departure has low scores represented by Poor and Very Poor condition classes across the country (figure A5.17). This indicates that the distribution of successional classes deviates from the expected distribution for many ecosystems (as defined in the biophysical settings from

LANDFIRE, Blankenship et al. 2021). All ecosystems (i.e., individual biophysical settings) have their own expected areal distribution across successional classes, and these distributions vary widely across ecosystems. Based on the indicator scores alone, however, it is not discernable if that deviation is due to over-representation of early, mid, or late seral stages. Further examination of the input data could help elucidate this, and it may be appropriate based on management objectives to have some departure on the landscape at any given time. If departure is from an over-representation of early seral, time may be needed to remedy the departure because it will allow some areas to grow into older successional classes. If departure is from an over-representation of late seral, that may be deemed acceptable because of the time needed for late seral to develop; however, management actions might be warranted to mitigate future disturbances depending on forest type, location, and local context (i.e., management objectives, community needs, and stakeholder perspectives). If the departure is from mid-seral, it might be worth hastening the development of late seral conditions through management activities depending on forest type and local conditions or promoting early seral stages for diversity.

Understanding the expected distribution of successional classes compared to the observed informs the types of management actions needed to promote MOG conditions into the future and to ensure age-class diversity appropriate to the ecosystem which can promote ecosystem resilience for when inevitable disturbances do occur.

Air Pollution

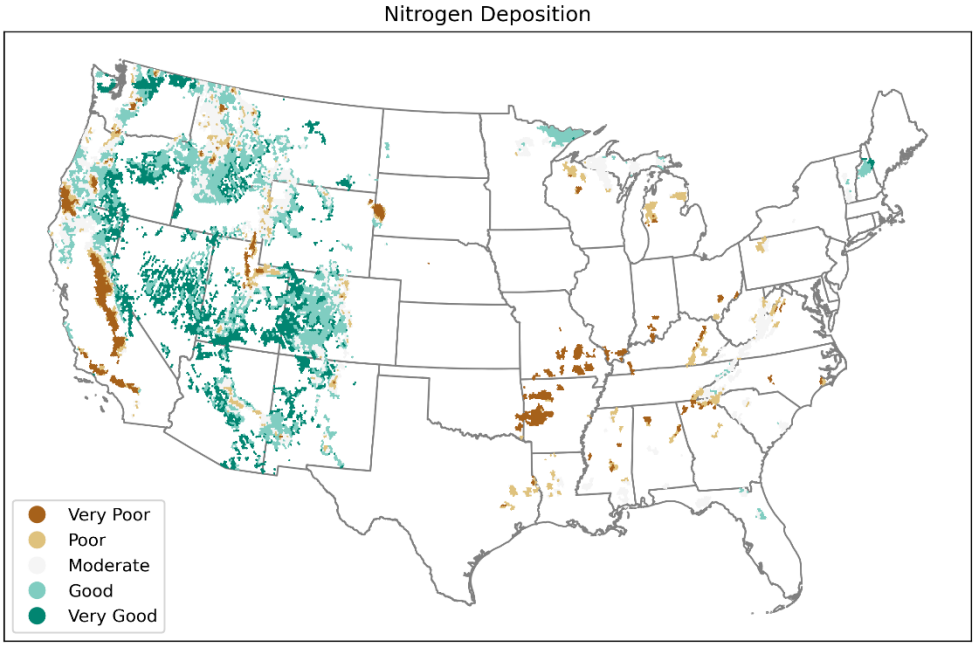

Figure A5.18.—Mapped condition classes of the Nitrogen Deposition metric for Project Areas containing federally owned forest land from the MOGCA model. The Nitrogen Deposition metric makes up the Air Quality indicator in the MOGCA model.

The Air Pollution indicator examines nitrogen deposition levels in the context of critical loads (i.e., levels of deposition when ecological impacts are observed) relevant to the region. Generally, areas downwind of large population areas have lower scores indicating more

exceedances of critical load levels for nitrogen deposition (figure A5.18). The critical loads used are related to decreases in biodiversity of lichens and herbaceous plants to determine initial ecological impacts from nitrogen deposition amounts elevated above background levels. Higher critical loads represent disruptions to ecological processes (e.g., hydrologic fluxes of nitrogen) and indicate more ecological impacts are likely as deposition levels increase. Most areas of the country have scores less than Very Good which indicate some level of nitrogen deposition above background rates to the point of having a likely impact on the ecosystem. More ecological impacts are more likely in areas with lower scores which correspond to higher levels of deposition.

Current Threats

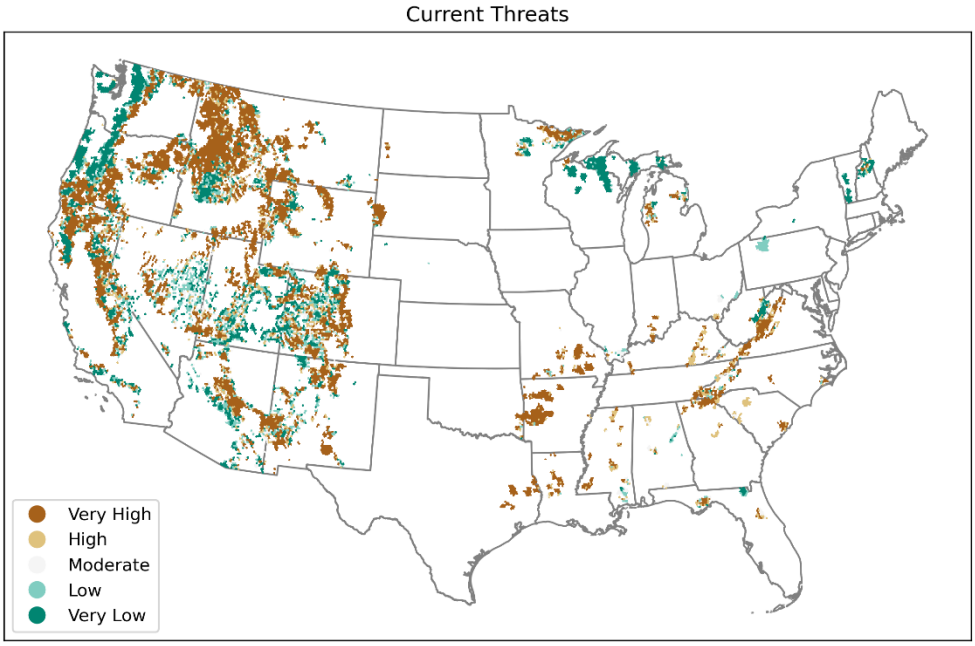

Figure A5.19.—Mapped condition classes of the Current Threats measure for Project Areas containing federally owned forest land from the MOGCA model. Current Threats are derived from three different potential threats analyzed by the MOGCA model: wildfire, insects and disease, and fire exclusion.

Different indicators representing different potential threats drive and contribute to the picture of the Current Threats across the country (figure A5.19). Over half of the Project Areas dominated by Fir-spruce-mountain hemlock, Ponderosa pine, Oak-hickory, Loblolly-shortleaf, Lodgepole, and Oak-gum-cypress are rated as having Very High threat (scores less than −0.6) by the MOGCA model (figure A5.20).

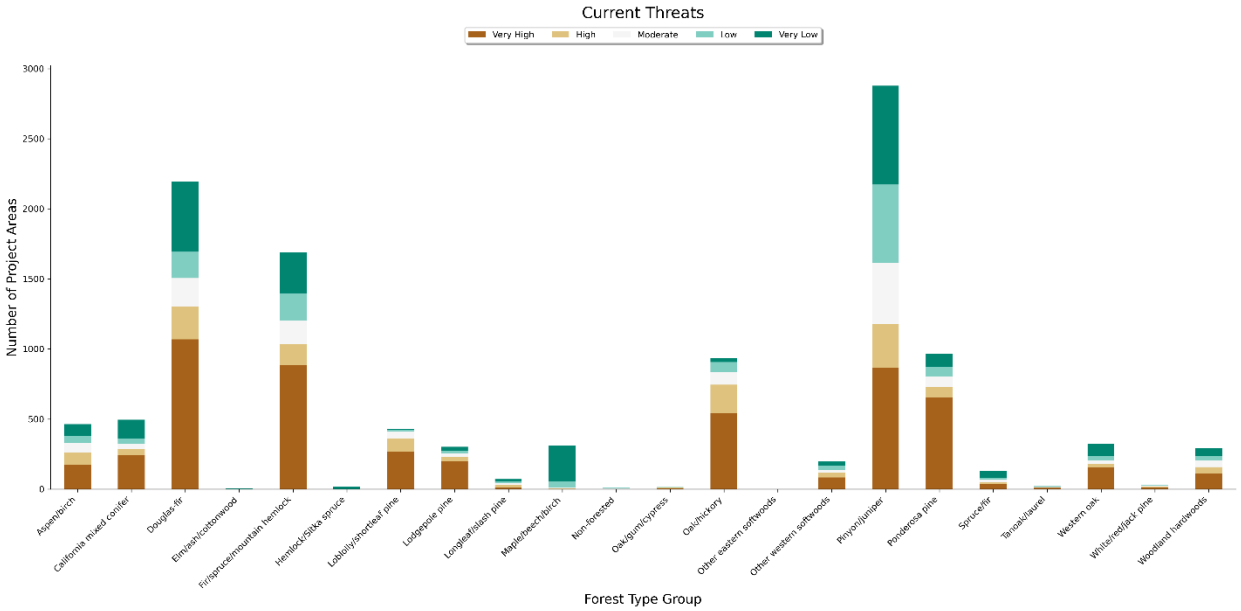

Figure A5.20.—The number of project areas by forest type group and condition class for the Current Threat measure which is determined by the scores (outcomes) of the Wildfire Threat to Late Seral Forests, Insect and Disease Hazard, and Fire Deficit indicators in the MOGCA model. Nationally, 5,324 Project Areas were in Very Poor condition, 1,379 in Poor condition, 1,310 in Moderate condition, 1,379 in Good condition, and 2,387 in Very Good condition.

Wildfire Threat to Late Seral Forest

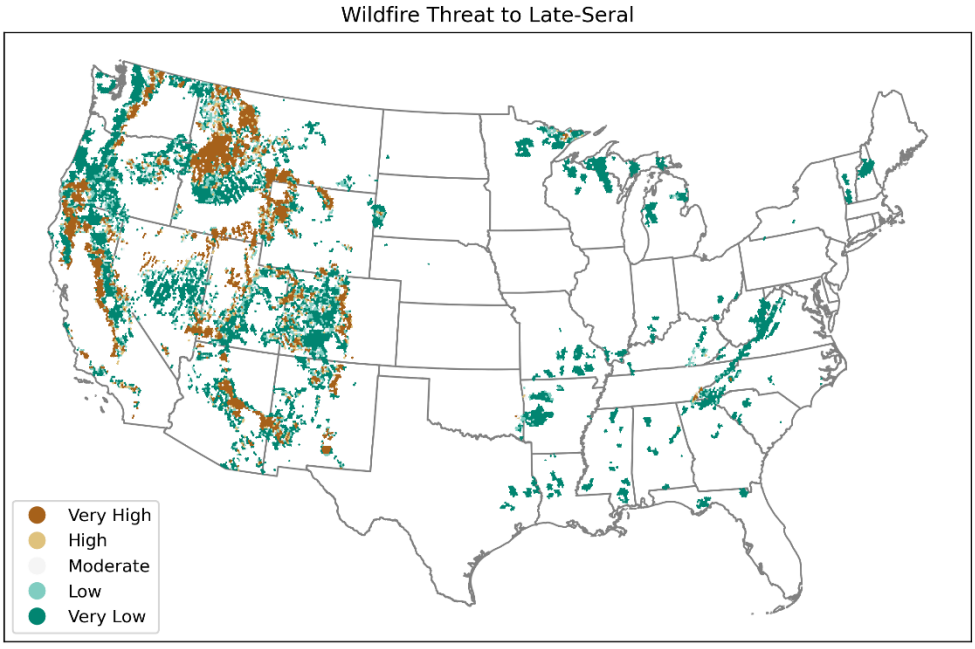

Figure A5.21.—Mapped condition classes of the Wildfire Threat to Late Seral Forest indicator for Project Areas containing federally owned forest land from the MOGCA model. This indicator represents the likelihood that fire could cause tree mortality to older forests defined as areas classified as late seral by LANDFIRE Successional Class data.

Wildfire Threat to Late Seral is focused on where the probability is high for wildfires that are damaging to the point of causing tree mortality and the loss of late seral forest (figure A5.21). This threat is highly concentrated with approximately 50 percent of the threat identified in the cumulative eNVC occurring in 7.6 percent of the Project Areas examined in this analysis, which represent about 10 percent of the federally forests areas. Nearly 2,500 Project Areas were rated with a very high threat for this measure, and they represent nearly 44 million acres of federally owned forest land. The highest threats to late seral forests are in Project Areas dominated by Western oak, Fir-spruce-mountain hemlock, Douglas fir, Pinyon-juniper, Lodgepole pine, and California mixed conifer (figure A5.22).

Of note, some Project Areas do not have late seral forest (as captured in the successional class data from LANDFIRE). These Project Areas are represented by null values for this indicator in the MOGCA model results.

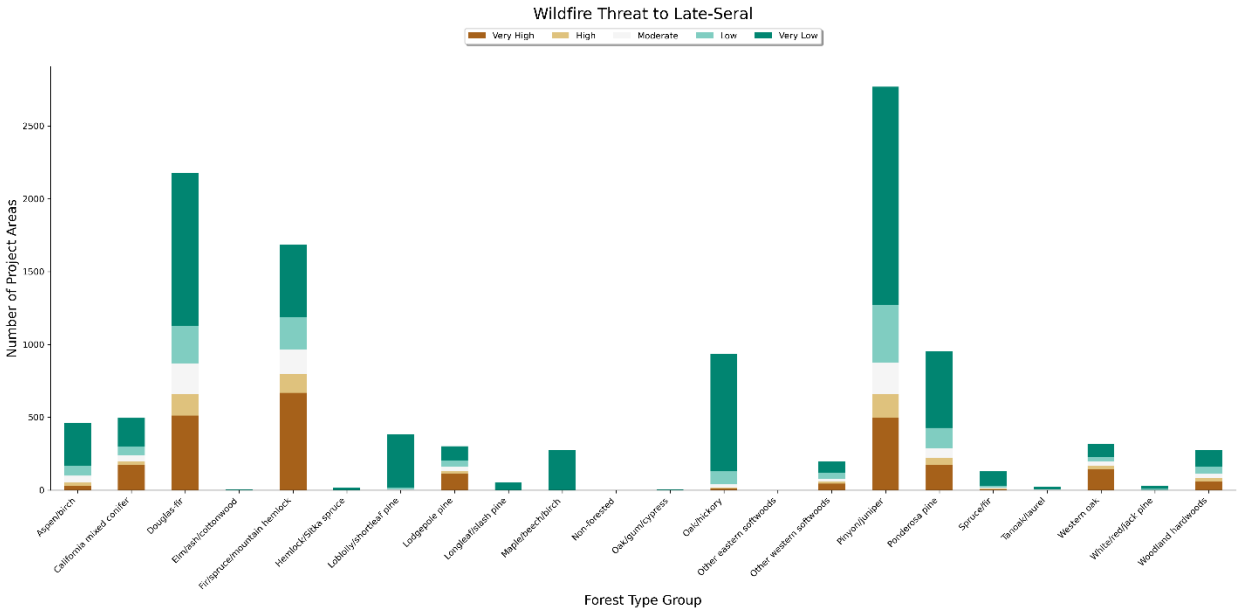

Figure A5.22.—The number of project areas by forest type group and condition class for the Wildfire Threat to Late Seral Forests indicator. Nationally, 2,427 project areas were in Very Poor condition, 636 in Poor condition, 886 in Moderate condition, 1,438 in Good condition, and 6,106 in Very Good condition.

Insect and Disease Hazard

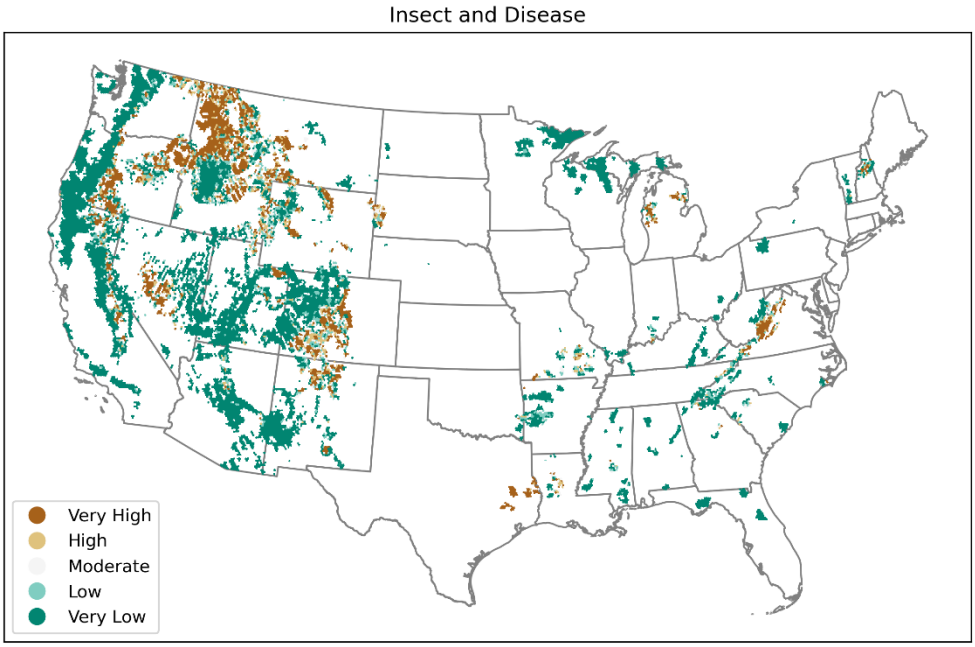

Figure A5.23.—Mapped condition classes of the Insect and Disease hazard indicator for Project Areas containing federally owned forest land from the MOGCA model. Insect and Disease hazard leverages the National Insect and Disease Risk Map to determine areas likely to experience significant tree mortality from insects and disease in the next 15 years.

High and Very High insect and disease hazard conditions were found in 2,712 Project Areas representing nearly 24.5 million acres or 25.3 percent of federally forested lands examined for this analysis (figure A5.23). Project Areas dominated by Douglas-fir, Fir-spruce-mountain hemlock, Pinyon-juniper, and Ponderosa pine forest types each have over 200 Project Areas rated as having very high potential threat as indicated by low scores in the MOGCA model (figure A5.24).

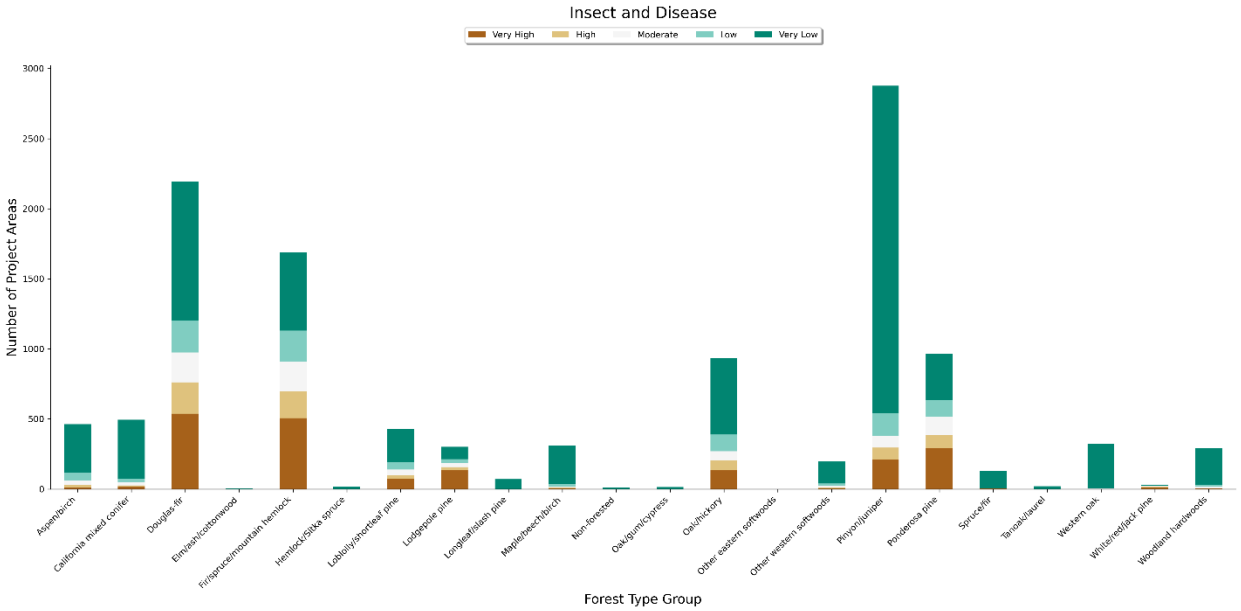

Figure A5.24.—The number of Project Areas by forest type group and condition class for the Insect and Disease Hazard indicator. Nationally, 1,960 Project Areas were in Very Poor condition, 752 in Poor condition, 863 in Moderate condition, 1071 in Good condition, and 7,129 in Very Good condition.

Fire Deficit

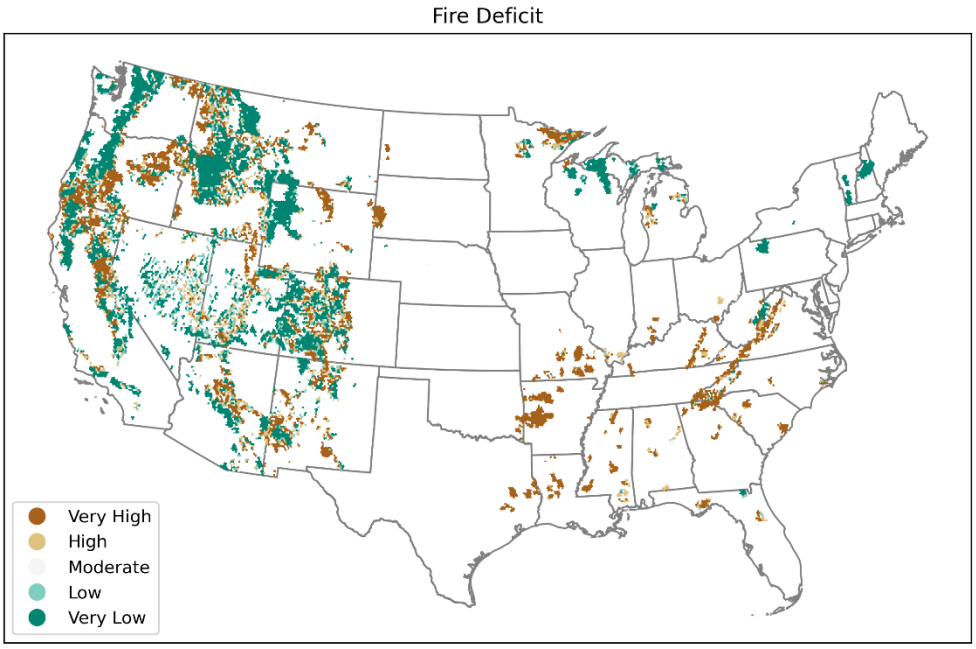

Figure A5.25.—Mapped condition classes of the Fire Deficit indicator for project areas containing federally owned forest land from the MOGCA model. Fire Deficit is identifying where ecosystems dependent on fire (based on mean fire return intervals) have not had fire at the ecologically appropriate frequency. This deficit is driven predominantly by fire exclusion.

Fire Deficit depicts the lack of fire occurring on the landscape which is usually the result of fire suppression and exclusion (figure A5.25). Reduced fire frequencies, especially in frequent fire

forested ecosystems, can lead to the buildup of fuels and limit ecological processes (e.g., regeneration of trees and herbaceous species) that depend on fire. Ecosystems where fire is infrequent compose many of the areas with Very Low threat. Many of the frequent fire ecosystems have not had fire occur throughout the 20th century, or fire has not occurred with the same frequency as it did historically. This is especially apparent in the Project Areas dominated by Loblolly-shortleaf pine and Oak-hickory forest types (figure A5.26). Frequent fires help lower fire intensities which promotes numerous ecological benefits of fires and can improve resiliency of the ecosystem.

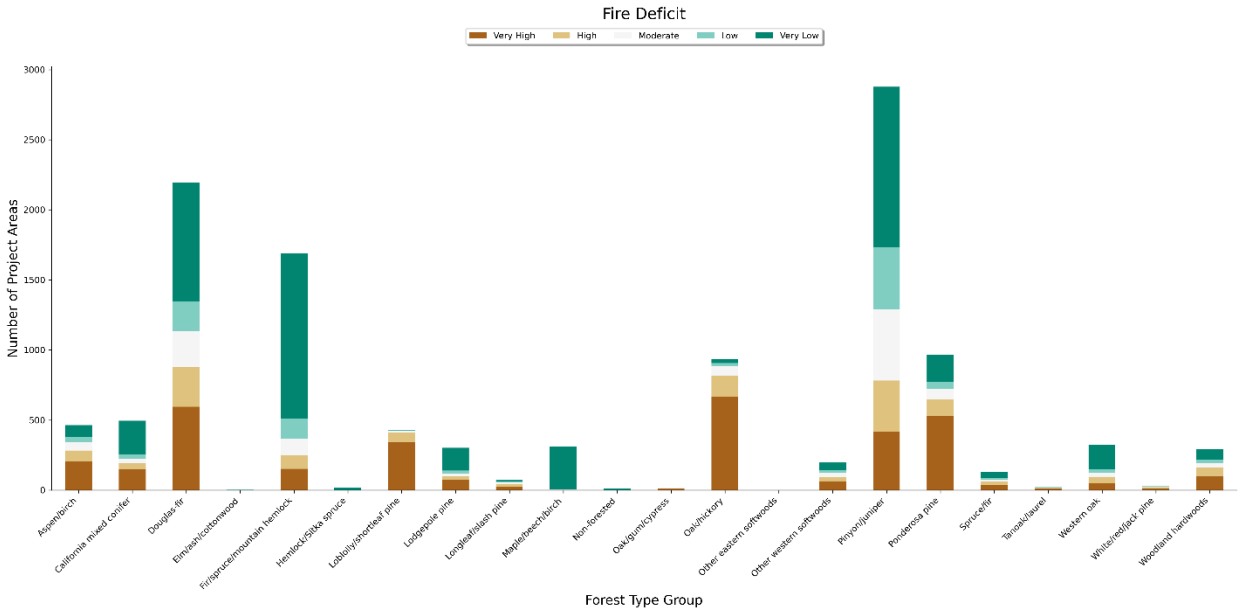

Figure A5.26.—The number of Project Areas by forest type group and condition class for Fire Deficit indicator. Nationally, 3,434 Project Areas were in Very Poor condition, 1,420 in Poor condition, 1,282 in Moderate condition, 1,054 in Good condition, and 4,589 in Very Good condition.

Appendix 6 – Regional Fire Summary

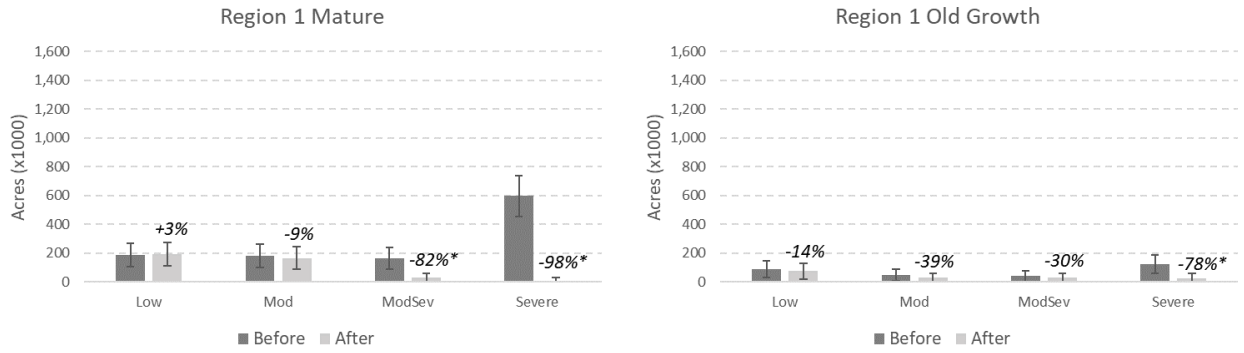

Figure A6.1.—Region 1 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after a fire disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).

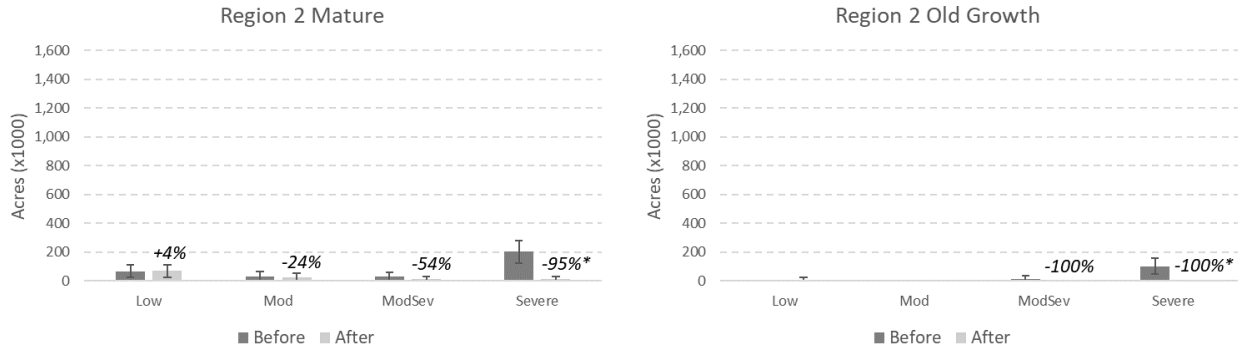

Figure A6.2.—Region 2 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after a fire disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).

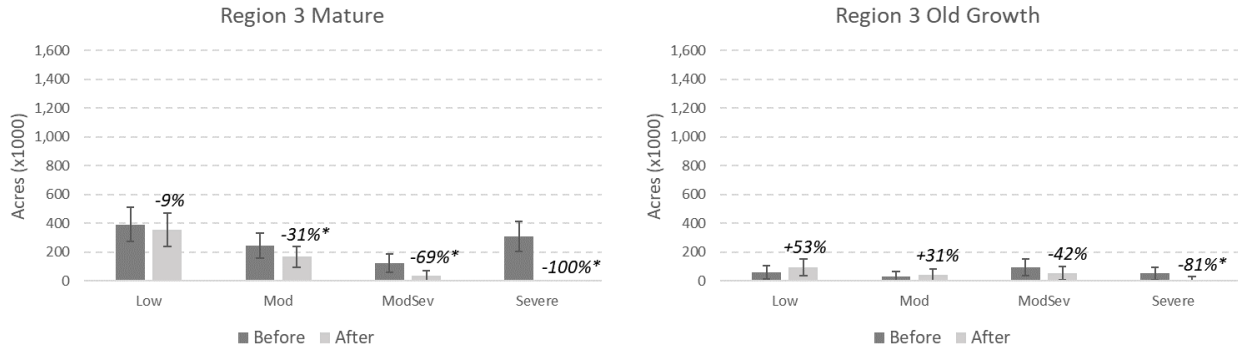

Figure A6.3.—Region 3 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after a fire disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90%

basal area mortality), or Severe (>90% basal area mortality).

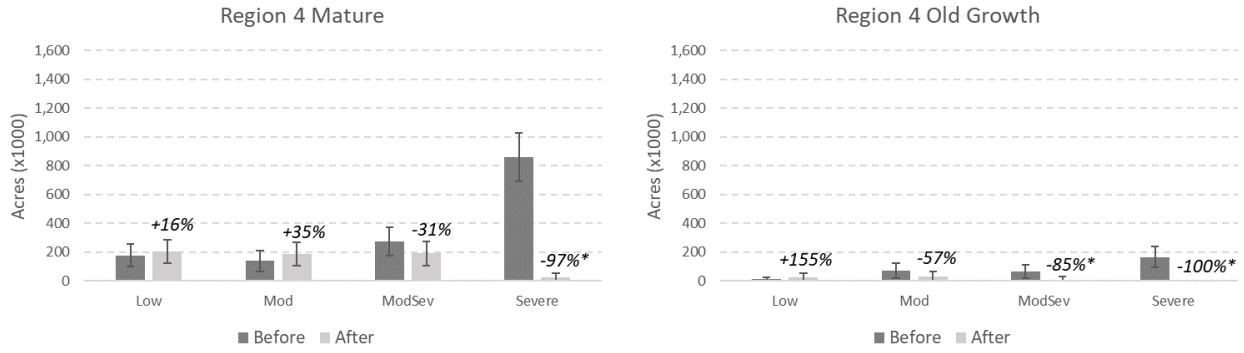

Figure A6.4.—Region 4 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after a fire disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).

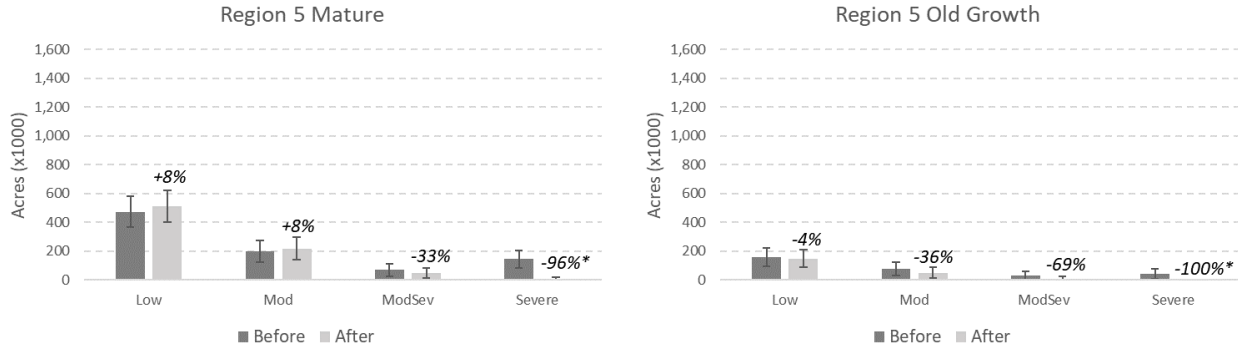

Figure A6.5.—Region 5 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after a fire disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).

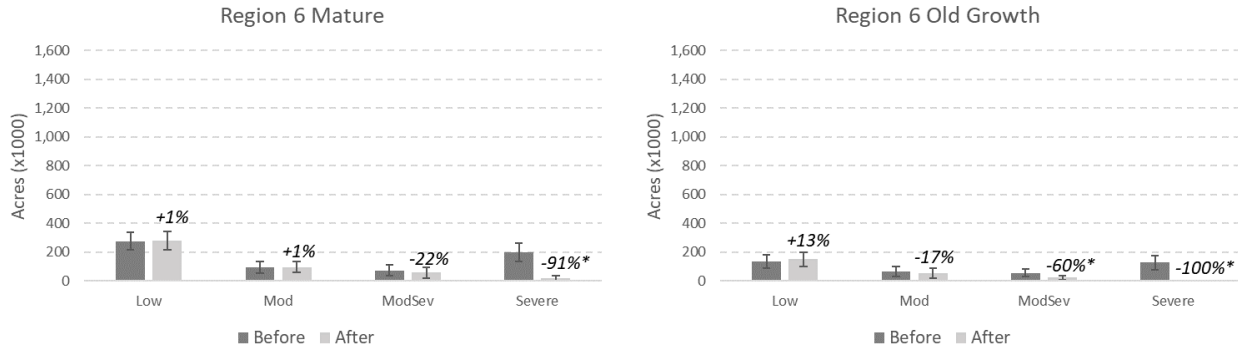

Figure A6.6.—Region 6 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after a fire disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).

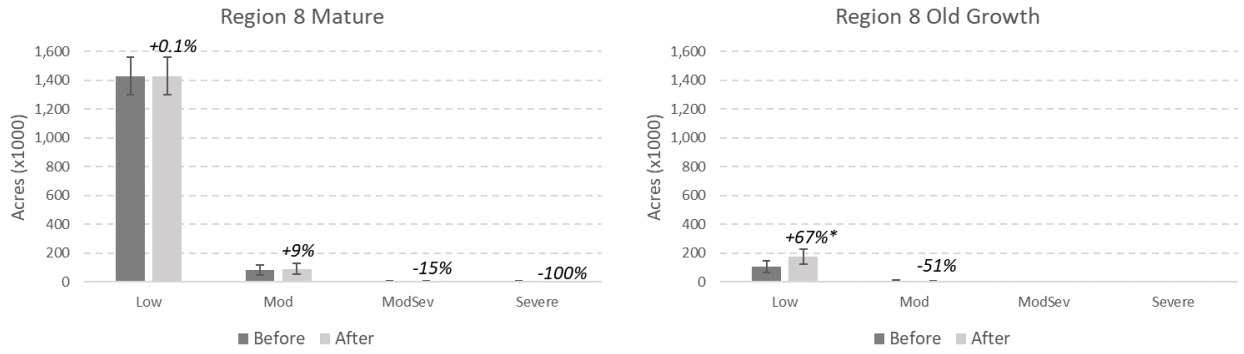

Figure A6.7.—Region 8 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after a fire disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).

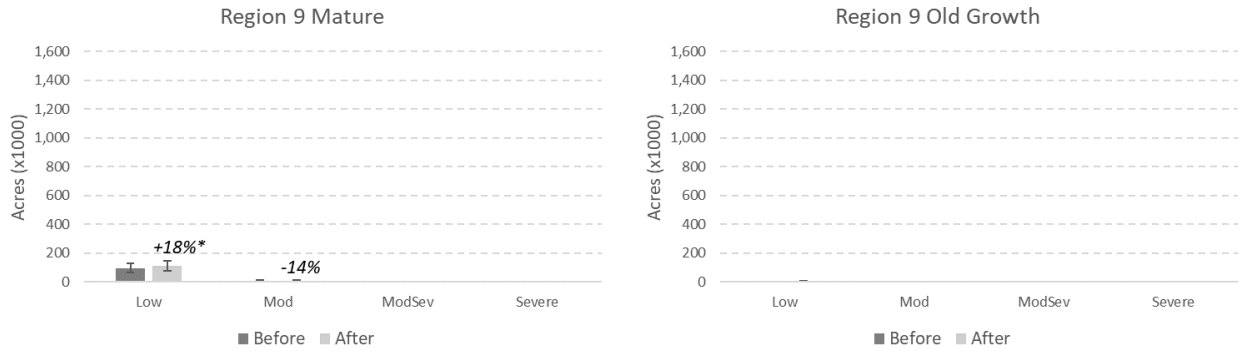

Figure A6.8.—Region 9 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after a fire disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality)..

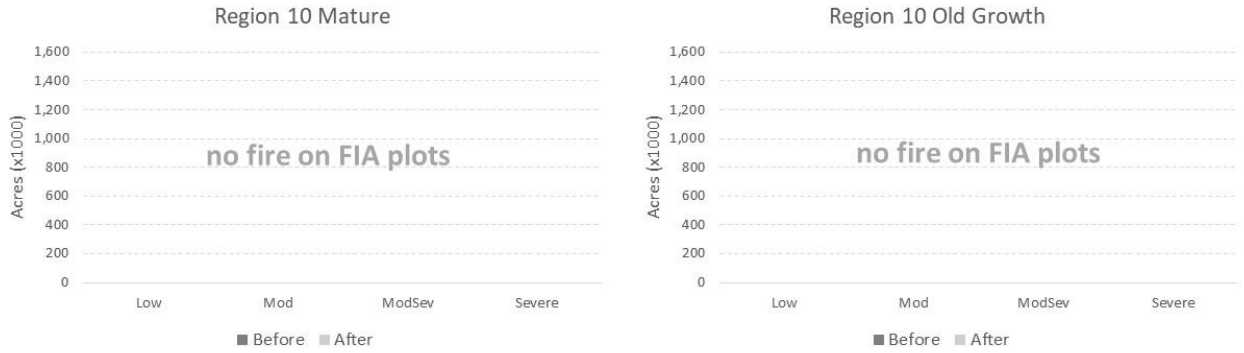

Figure A6.9.—Region 10 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after a fire disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).

Figure A6.10.— Regional variations in fire disturbance severity (based on live tree basal area mortality) for mature and old-growth forests. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).

Appendix 7 – Monitoring Trends in Burn Severity Analysis

A comparison (masked to forest land) between the National Burn Probability (BP) map (Dillon et al. 2023) and the fire risk map from Anderegg et al. (2022) was done to inform how the National BP map compares to fire exposure classes used for the mature and old-growth (MOG) forest threat analysis (main document, table 2). Both maps in (shown in figure A7.1) are based on continuous model outputs that were reclassified into five map classes (table A7.1).

Table A7.1.—Map class thresholds for the continuous model outputs for the National BP and Anderegg maps.

Map Class	National Burn Probability (2023) Annual probability of a fire	Anderegg et al. (2022) Annual percent area burned by moderate- to high-severity fire[5]
Very low	≤ 0.000100	≤ 0.000072
Low	0.000100–0.000464	0.000072–0.000494
Moderate	0.000464–0.002154	0.000494–0.000825
High	0.002154–0.010000	0.000825–0.001562
Very high	>0.010000	>0.001562

In appearance, the classified maps are very similar in the western contiguous United States (US), but not in eastern US. The main reason for this difference is that the National BP map represents the annual probability of wildfire of *any* severity (low to high); whereas the Anderegg et al. (2022) map represents the probability (defined by them as "risk") of only moderate- to high-severity wildfire. Based on Monitoring Trends in Burn Severity (MTBS) data (https://www.mtbs.gov/) moderate- to high-severity fire comprises a much smaller proportion of area burned in the eastern US than it does in the West. Thus, the National BP map shows less "very low" and more "moderate to high" map classes in the East than the Anderegg map does.

[5] Fire risk was modelled as a fraction of a 4-km grid cell burned per year.

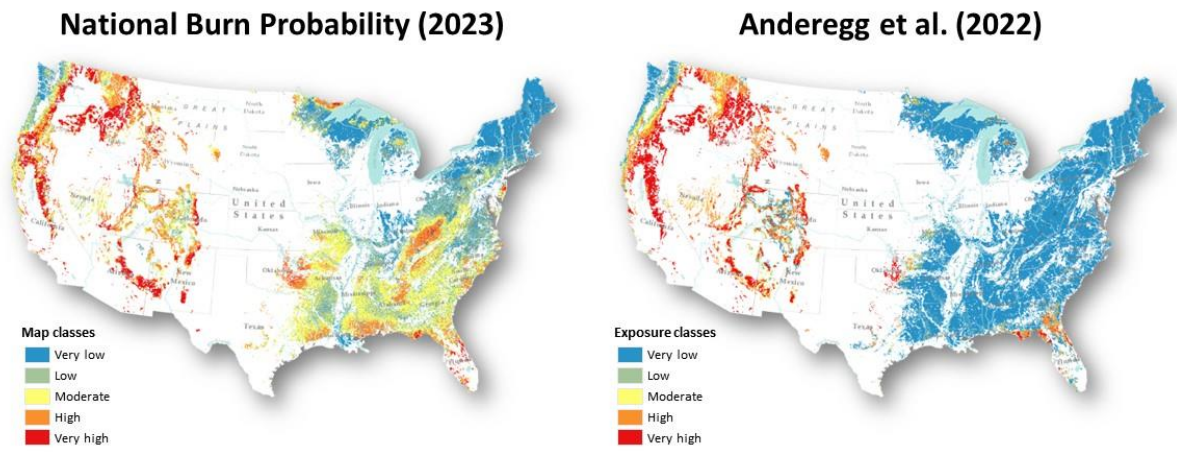

Figure A7.1.—A side-by-side visual comparison of the National Burn Probability map (L) with the Anderegg et al. (2022) map ®.

An additional MTBS analysis was done for two time periods to understand the relationship between exposure classes in the Anderegg map and forest area burned (figure A72). The analysis was conducted on all forests, since a map of mature and old-growth forest based on inventory definitions (USDA and USDA 2023) was not available. The analysis was masked to NFS and BLM forest lands with firesheds.

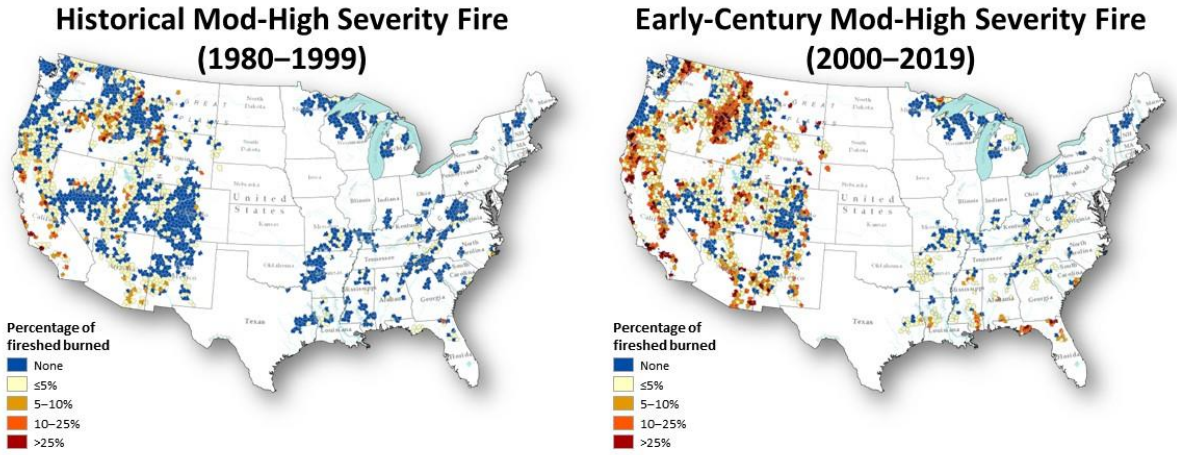

Figure A7.2.—Fireshed analysis based on percentage of forests on NFS and BLM lands burned by large (>1,000 ac in the west and 500 ac in the east) moderate- to high-severity fire using Monitoring Trends in Burn Severity (MTBS) data.

The area burned at moderate- to high-severity fire during the early-century (2.5 million ac) was more than 4-times what was burned during the historical period (0.6 million acres). Table A7.2 shows total and an annual average percentage of NFS and BLM forests burned for each map exposure class (combined across all firesheds) for the historical period (1980–1999) and early-century period (2000–2019).

Table A7.2.—Proportion (total and averaged annually) of NFS and BLM forest burned by moderate to high-severity wildfires. Historical data for Monitoring Trends in Burn Severity only extends back to 1984.

Exposure Class	Historical (1984–1999) Total (%)	Historical (1984–1999) Annual (%)	Early Century (2000–2019) Total (%)	Early Century (2000–2019) Annual (%)
Very low	0.09	0.005	0.65	0.033
Low	0.46	0.023	1.40	0.070
Moderate	1.75	0.088	2.86	0.143
High	2.27	0.113	6.66	0.333
Very high	2.94	0.147	10.61	0.530

The results of this analysis show that the forested area burned by moderate- to high-severity wildfires has increased since recent historical records (1984–1999). A result that is consistent with Anderegg et al. (2022) that indicated fire risks are projected to increase by a factor of >4 for throughout the 21st century.

Appendix 8 – Resources Planning Act Assessment of Future Mature and Old-Growth Forests

Background on the RPA Forest Dynamics Model and RPA Scenarios

The Resources Planning Act (RPA) Forest Dynamics Model is a stochastic modeling system that projects the FIA database at the plot (condition) level using an imputation approach (Coulston et al. 2023). This approach allows for consistent projections that are based on the observed relationships among FIA variables at the plot level through the projection period. The Forest Dynamics Model is informed by exogenous variables including climate, timber prices, human population, and income, as well as by a set of sub-models representing harvest choices, forest disturbance, growth, aging, regeneration, and forest type transitions over time. The Forest Dynamics Model was only applied to FIA plots that meet the RPA definition of forest land, which is a subset of all FIA forest land and matches international forest land definitions. The RPA forest land definition has a minimum height requirement and excludes some woodlands, primarily in the southwestern U.S. (Oswalt et al. 2019).

The 2020 RPA Assessment includes projections of forest conditions and areas from the Forest Dynamics Model for the contiguous U.S. for the period 2020-2070 under a set of future scenarios that incorporate warming, socioeconomic growth, and alternative climate models. The RPA scenarios pair two alternative climate futures (Representative Concentration Pathways, or RCPs) with four alternative socioeconomic futures (Shared Socioeconomic Pathways, or SSPs) in the following combinations: RCP 4.5 and SSP1 (lower warming-moderate U.S. growth, LM), RCP 8.5 and SSP3 (high warming-low U.S. growth, HL), RCP 8.5 and SSP2 (high warming-moderate U.S. growth, HM), and RCP 8.5 and SSP5 (high warming-high U.S. growth, HH) (see O'Dea et al. 2023 for more information on scenarios). The 2020 RPA Assessment pairs these four RPA scenarios with five different climate models that capture the wide range of projected future temperature and precipitation across the contiguous United States (O'Dea et al. 2023, Joyce and Coulson 2020).

For this analysis, the national forest dynamics model projections from the 2020 RPA Assessment were summarized specifically for mature and old growth forests on Forest Service and BLM lands across the contiguous U.S. and for RPA regions (figure A7.1). We present projected trends in mature and old growth forest areas, areas of forest land burned by wildfires, and harvest removal volumes. Importantly, while the areas of mature, old growth, and younger forests change over time in these projections, no land use change occurs on Forest Service and BLM lands in the Forest Dynamics Model, so the total area of forest land remains constant for those ownerships. Furthermore, because the projections are based on the FIA inventory, sampling error associated with inventory design is inherent in these projections, remains constant over time at 2020 levels for all variables projected, and is not shown in the figures, although the sampling

error associated with individual realizations comprises a portion of the variability across model realizations.

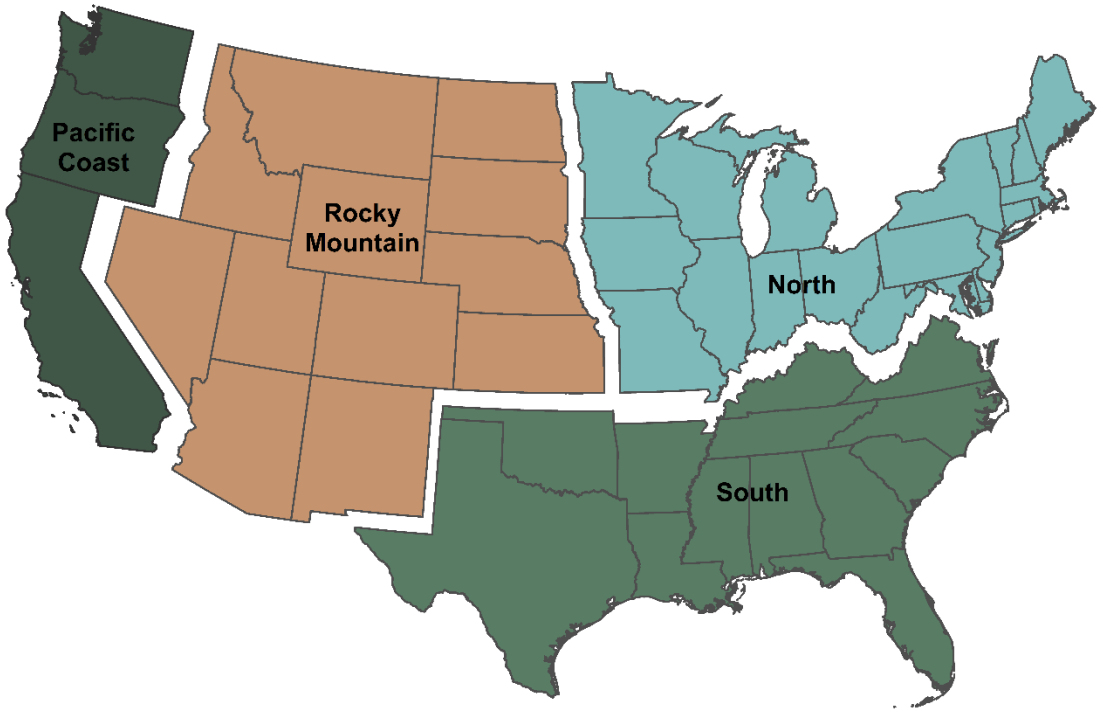

Figure A8.1.—Resources Planning Act Assessment regions within the contiguous United States.

Projected Mature and Old-growth Forest Areas

Forest Dynamics Model projections indicate an increase over the next 50 years in old growth forest area on Forest Service and BLM land in the contiguous U.S. This trend is consistent across scenarios that combine levels of warming and socioeconomic growth, and across the climate models analyzed within each of those scenarios (figure A7.2). Projections also indicate a decrease in younger forest across all scenarios and climate models. The area of mature forest is expected to remain steady or increase or decrease slightly depending on the scenario and climate model. The projections show regional differences in area change, with old growth increasing in the Rocky Mountains, the Pacific Coast, and the North, but increasing or decreasing depending on the scenario in the South (Figure A8.3; only the high warming / moderate growth scenario is shown here). Mature forest, meanwhile, may increase in the North and Pacific Coast Regions while remaining relatively steady in the Rocky Mountains and the South. These results indicating an increase in old growth area and a decrease in younger forest area are consistent with the overall forest succession and aging trends projected for all forests in the contiguous U.S. in the 2020 RPA Assessment (Coulston et al. 2023).

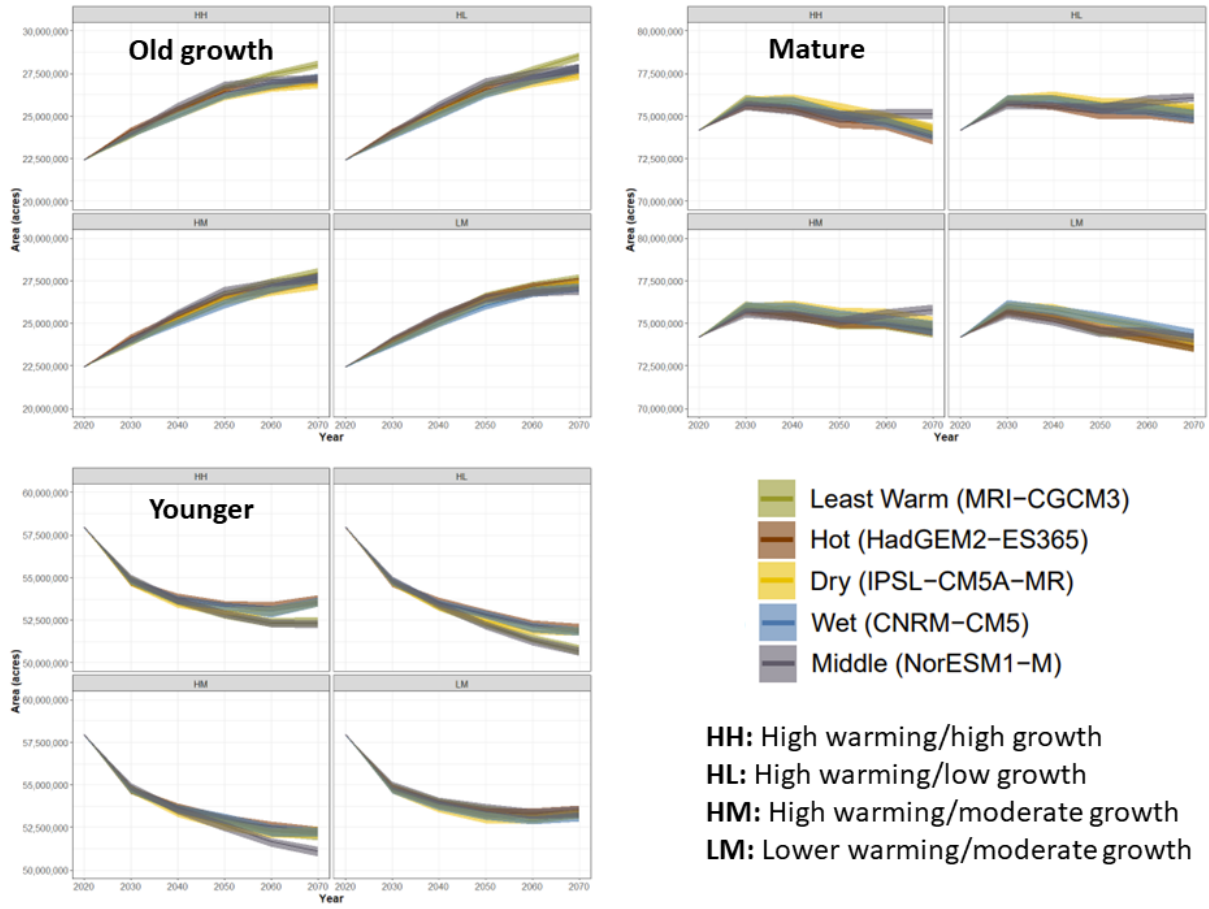

Figure A8.2.—Acres of old growth, mature, and younger forest on Forest Service and Bureau of Land Management land in the contiguous United States until 2070, projected by the Resources Planning Act Assessment Forest Dynamics Model. For each curve, the dark line represents the median projection across 100 replications of the model. The shading represents the interquartile range (middle 50%) of the 100 replications. Note the difference in the scale of the y-axes. Climate models are represented by colors, and results for each scenario are shown in separate panels.

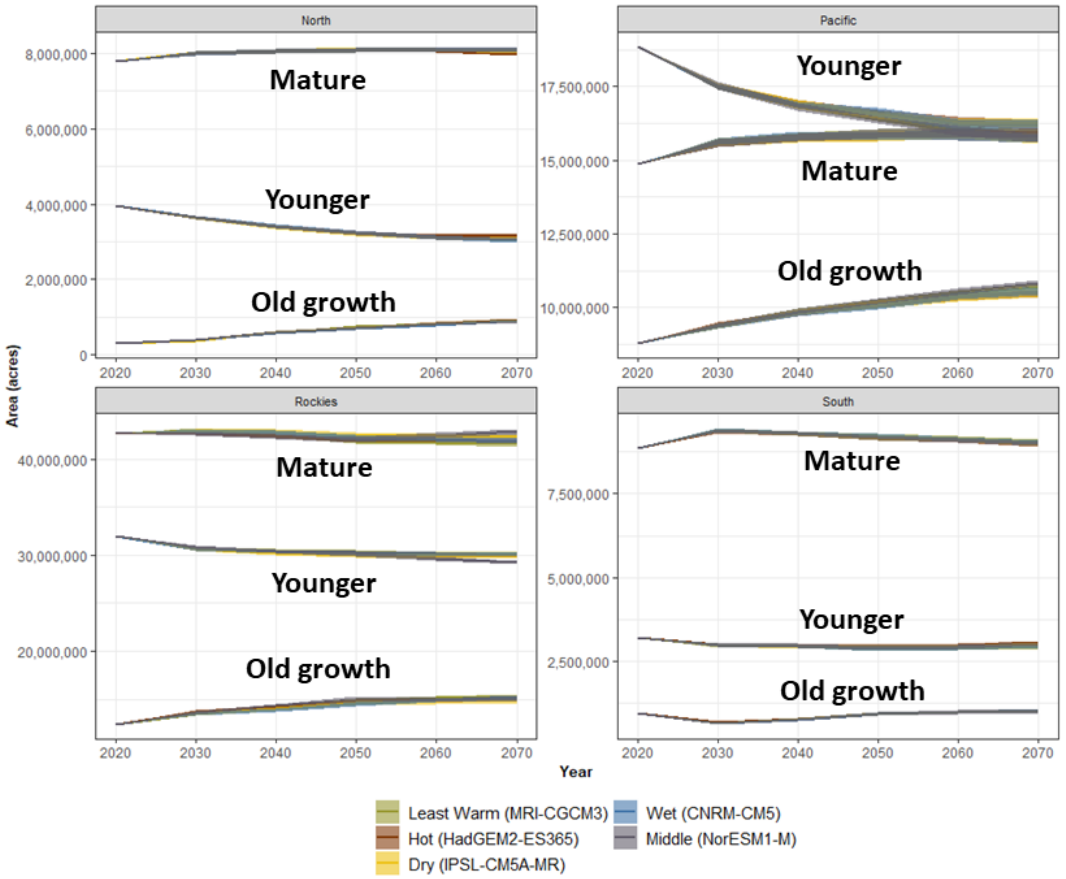

Figure A8.3.—Acres of old growth, mature, and younger forest on Forest Service and Bureau of Land Management land by region until 2070, projected by the Resources Planning Act Assessment Forest Dynamics Model, for the high warming/moderate growth scenario only. For each curve, the dark line represents the median projection across 100 replications of the model. The shading represents the interquartile range (middle 50%) of the 100 replications. Climate models are represented by colors. The other three scenarios showed similar trends. Note the difference in the scale of the y-axes on each panel.

Wildfire

The Forest Dynamics Model contains a sub-model that projects the future fire occurrence and tree mortality resulting from fire based on FIA data, and links to other sub-models that modify forest characteristics over time, including basal area, down woody material that can act as fuels, stand age, species composition, and harvest probability. Because of the limited ability of FIA field crews to detect low-severity fires, fires that do not lead to tree mortality are omitted from the Forest Dynamics Model. Thus, the projections can be used to examine changes in annual areas burned by moderate and high severity wildfires over time (Costanza et al. 2023).

The Forest Dynamics Model projects increases in annual area burned by moderate to high severity wildfires for both old growth and mature forest across most scenarios and climate models (Figure A8.4). For old growth forests, annual area burned is projected to increase by 2070 compared with 2020 in the hot (HadGEM2-ES365), dry (IPSL-CM5A-MR), and wet (CNRM-CM5) climate models in all scenarios, while the largest decreases were projected for the

least warm (MRI-CGCM3) climate model in the high warming/high growth and high warming/low growth scenarios. For mature forests, annual area burned is expected to increase by 2070 compared with 2020 in all scenarios and climate models, with the greatest increases expected in the hot and dry models in the three scenarios with high warming. Projected values of annual area burned by 2070 for both mature and old growth forest show greater variability across climate models in each of the high warming scenarios than for the low warming scenario. In all regions and in all time steps, the annual area burned is relatively small compared to the overall areas of mature and old growth forests.

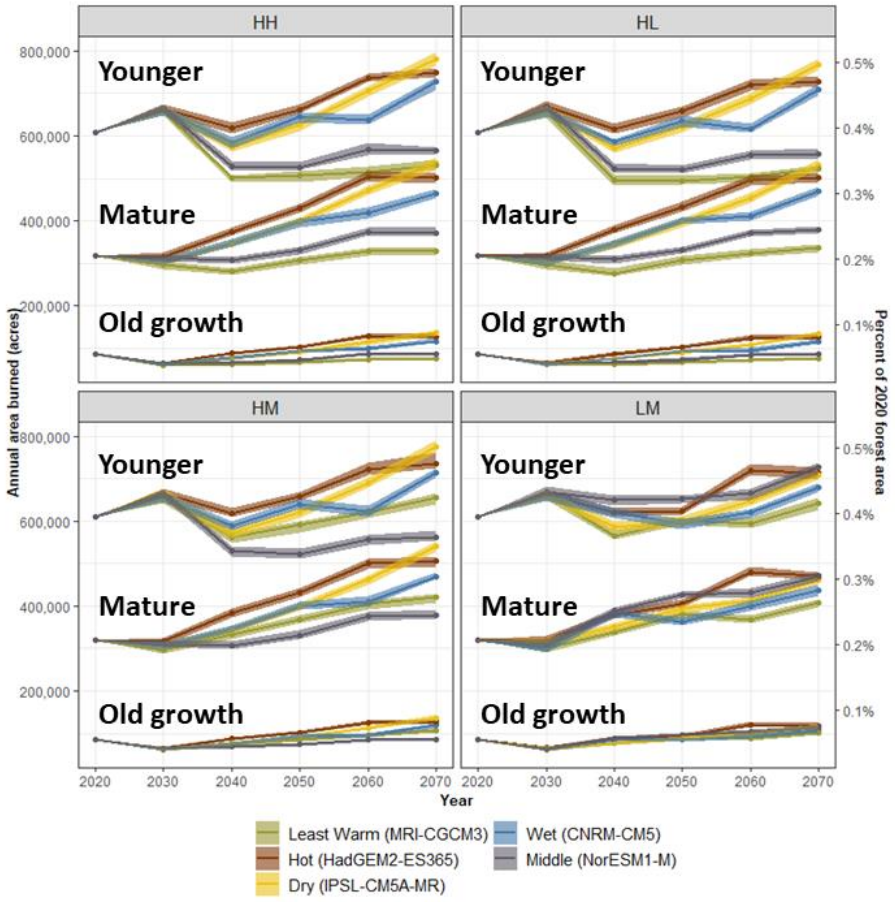

Figure A8.4.—Annual area burned (in acres) of old growth, mature, and younger forest on Forest Service and Bureau of Land Management land in the contiguous United States until 2070, projected by the Resources Planning Act Assessment Forest Dynamics Model. For each curve, the dark line represents the median projection across 100 replications of the model. The shading represents the interquartile range (middle 50%) of the 100 replications. Climate models are represented by colors, and results for each scenario are shown in separate panels. The secondary y-axis indicates the proportion of total Forest Service and BLM forest land in 2020 that corresponds to the given annual area burned.

The area of old growth forest burned annually by moderate to high severity wildfires is projected to generally increase by 2070 across climate models for the Rocky Mountain and North regions, remain relatively steady or decrease in the South, and decrease under all climate models in the Pacific Coast (Figure A8.5). Annual area burned in mature forests is projected to generally

increase by 2070 compared with 2020 in all regions in all climate models. The projected increases in area burned annually for mature forests are consistent with the overall increases in annual area burned for all forests in most futures in the 2020 RPA Assessment.

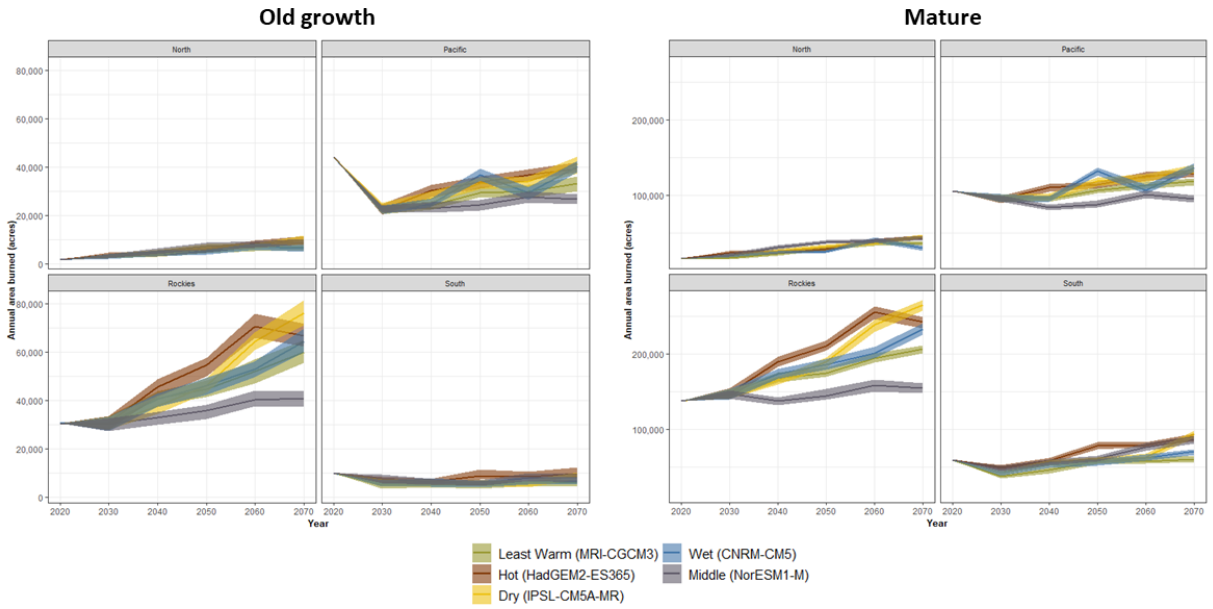

Figure A8.5.—Annual area burned (in acres) on old growth and mature forest on Forest Service and Bureau of Land Management land by region until 2070, projected by the Resources Planning Act Assessment Forest Dynamics Model, for the high warming/moderate growth scenario only. For each curve, the dark line represents the median projection across 100 replications of the model. The shading represents the interquartile range (middle 50%) of the 100 replications. Climate models are represented by colors. The other three scenarios showed similar trends. Note the difference in the scale of the y-axes for old growth and mature.

Tree Cutting

The Forest Dynamics Model contains a sub-model that projects harvest choices, and, like the wildfire sub-model, it links to other sub-models that modify forest characteristics over time. In the model, choices about harvests are linked to forest conditions, prices, and demand for wood over time nationally and globally, and reflect the empirical relationships between those endogenous and exogenous drivers and harvest. These relationships are modeled separately by RPA region, and vary by ownership, so that the historic price sensitivities of different forest ownership categories are empirically captured in the models.

We summarized volumes of harvest removals over time from the Forest Dynamics Model. The model projects increases in tree removal volumes from mature and old growth forests over the projection period, with the largest increases by 2070 occurring under the high warming/high growth and the lower warming/moderate growth scenarios (Figure A8.6). Increases in removals for both old growth and mature forests are more moderate under the high warming/low growth and high warming/moderate growth scenarios. These trends are consistent across regions, with particularly large growth in harvested volumes under the high warming/high growth and the lower warming/moderate growth scenarios for mature forests in the Pacific and South and for old

growth forests in the Pacific (Figure A8.7). The greater increases in removals by 2070 under the high warming/high growth and lower warming/moderate growth scenarios are consistent with the projections for all forest land summarized in the 2020 RPA Assessment; these increases are attributed in that assessment to the greater use of bioenergy in the LM and HH scenarios (Coulston et al. 2023).

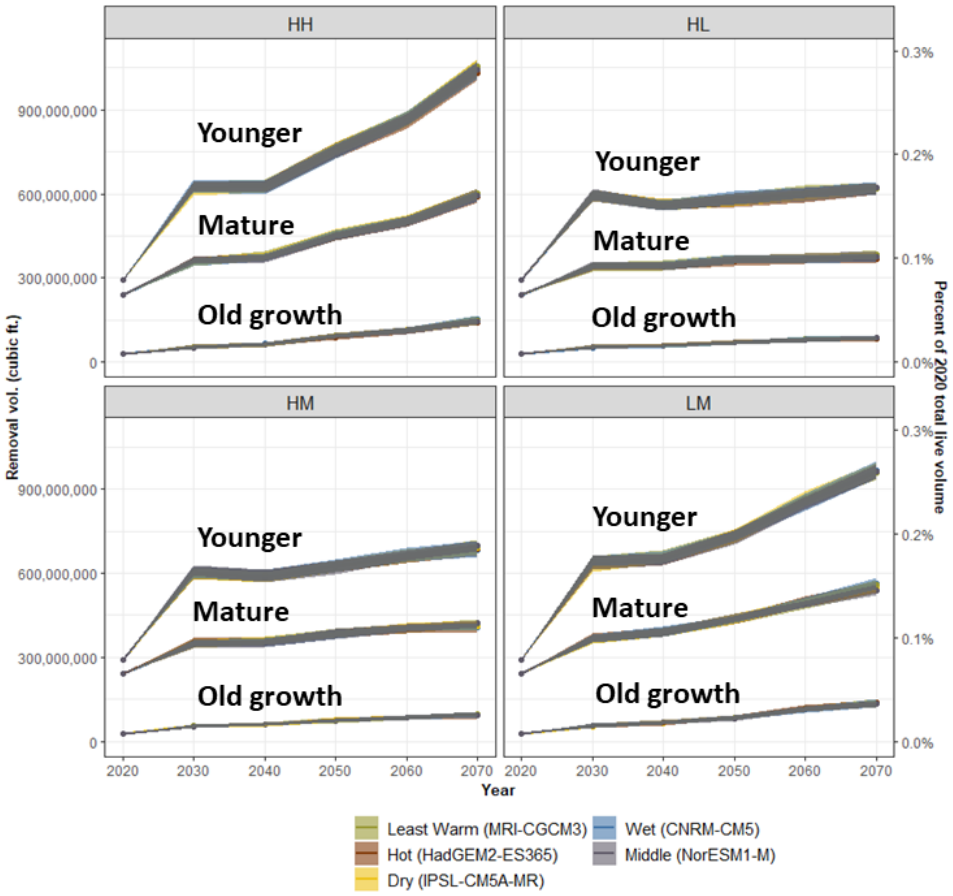

Figure A8.6.—Annual harvested volume of trees (in cubic feet) from old growth, mature, and younger forest on Forest Service and Bureau of Land Management land in the contiguous United States until 2070, projected by the Resources Planning Act Assessment Forest Dynamics Model. For each curve, the dark line represents the median projection across 100 replications of the model. The shading represents the interquartile range (middle 50%) of the 100 replications. Climate models are represented by colors, and results for each scenario are shown in separate panels. The secondary y-axis indicates the proportion of total live volume on Forest Service and BLM forest land in 2020 that corresponds to the given annual removal volume.

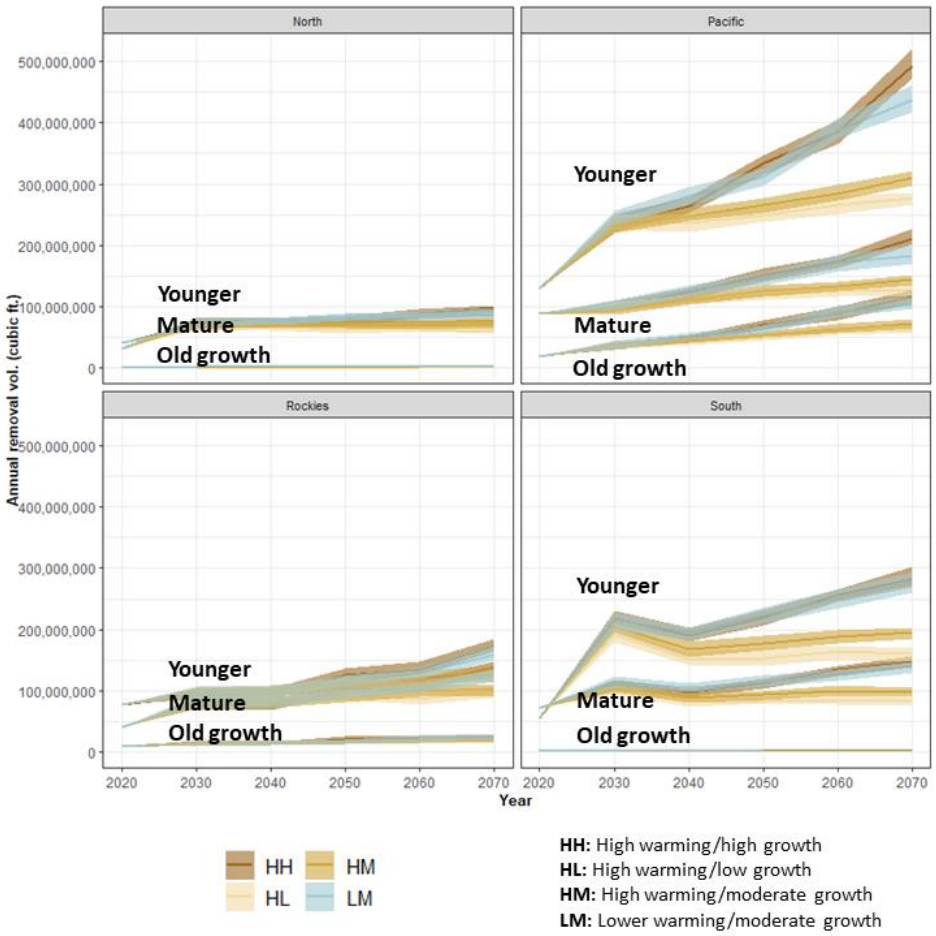

Figure A8.7.—Annual harvested volume of trees (in cubic feet) from old growth and mature forest on Forest Service and Bureau of Land Management land by region until 2070, projected by the Resources Planning Act Assessment Forest Dynamics Model, for the middle climate model (NorESM1-M) only. For each curve, the dark line represents the median projection across 100 replications of the model. The shading represents the interquartile range (middle 50%) of the 100 replications. The other climate models showed similar trends.

Appendix 9 – Regional Insect and Disease Summary

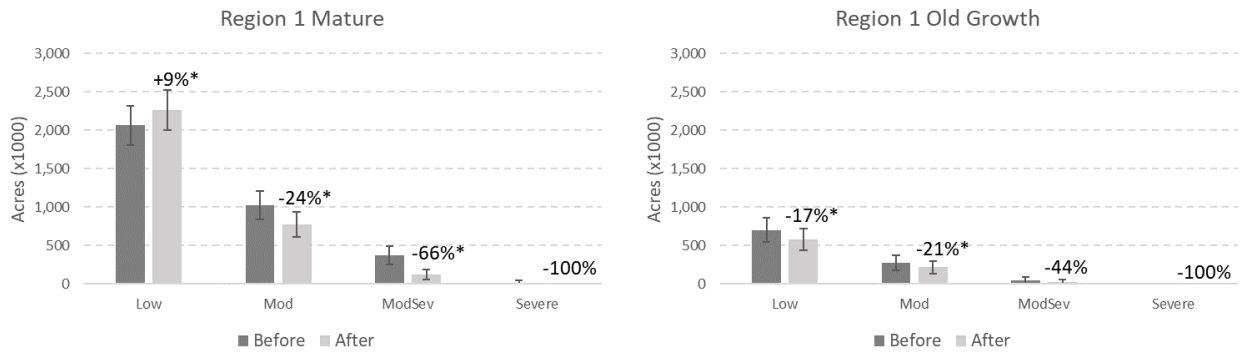

Figure A9.1.—Region 1 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after an insect/disease disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).

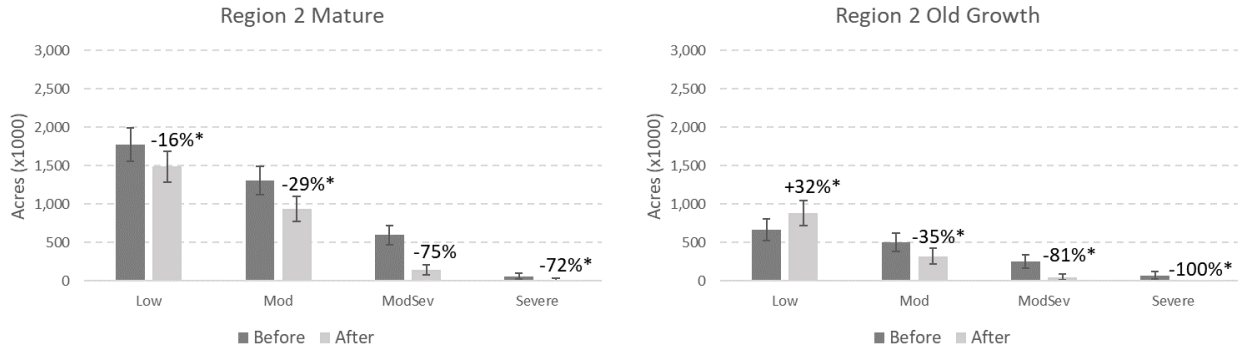

Figure A9.2.—Region 2 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after an insect/disease disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).

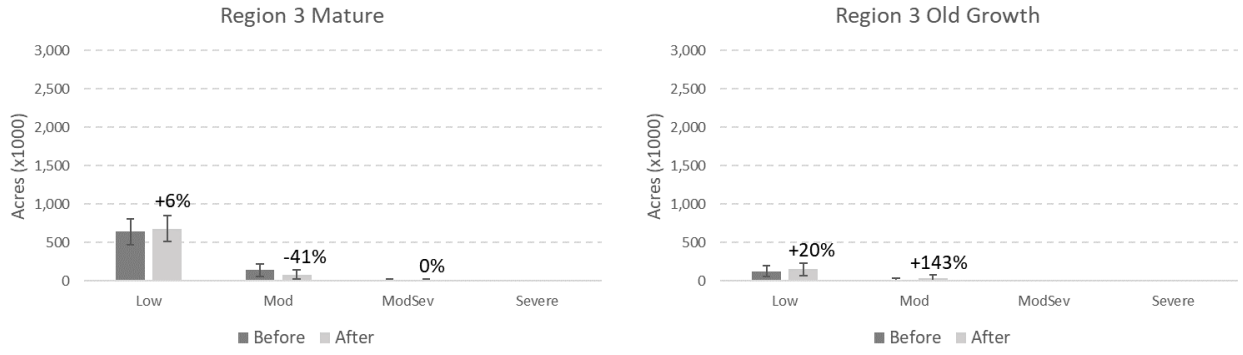

Figure A9.3.—Region 3 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after an insect/disease disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).

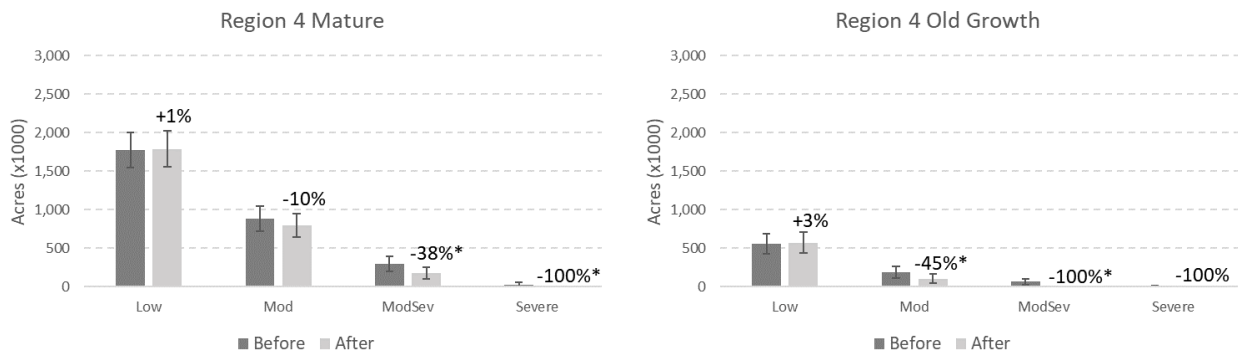

Figure A9.4.—Region 4 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after an insect/disease disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).

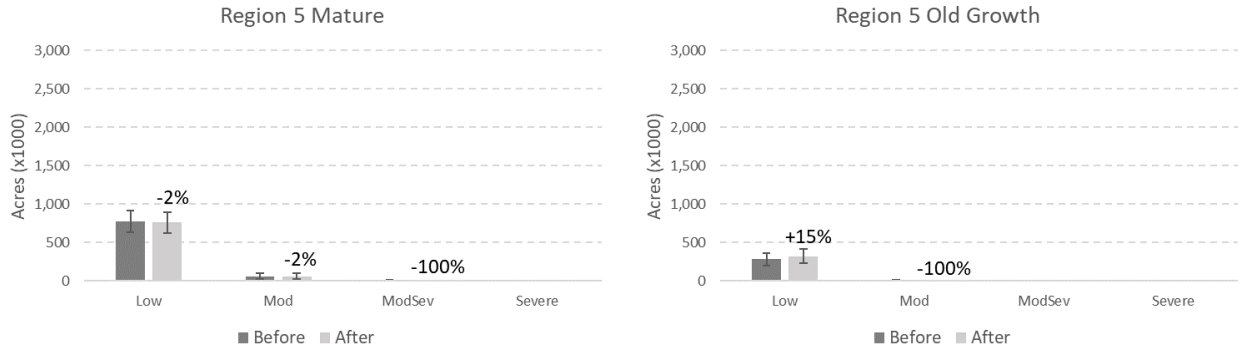

Figure A9.5.—Region 5 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after an insect/disease disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).

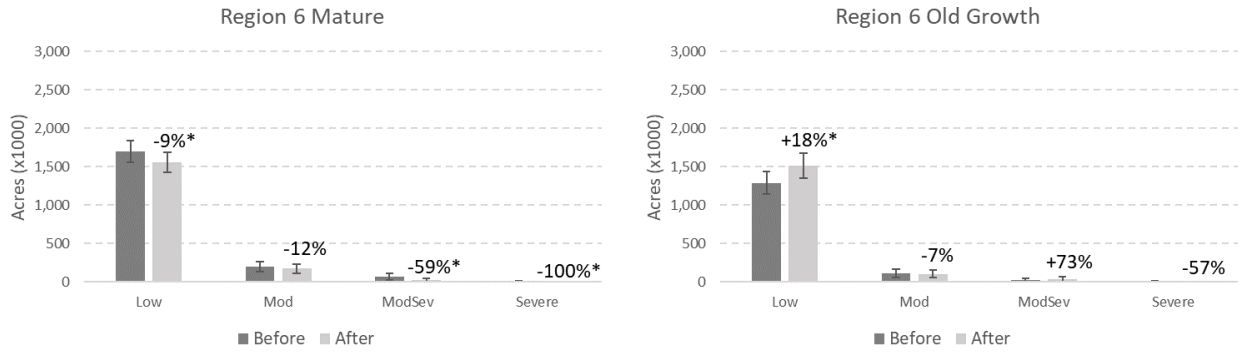

Figure A9.6.—Region 6 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after an insect/disease disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).

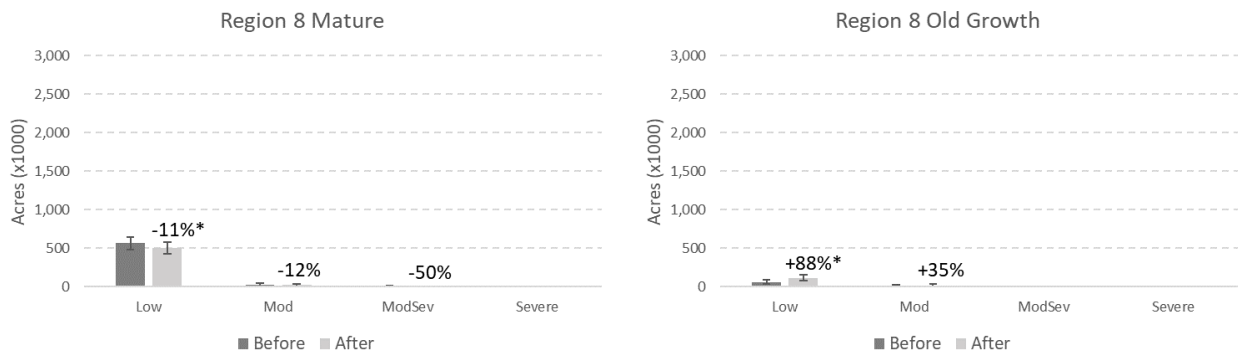

Figure A9.7.—Region 8 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after an insect/disease disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).

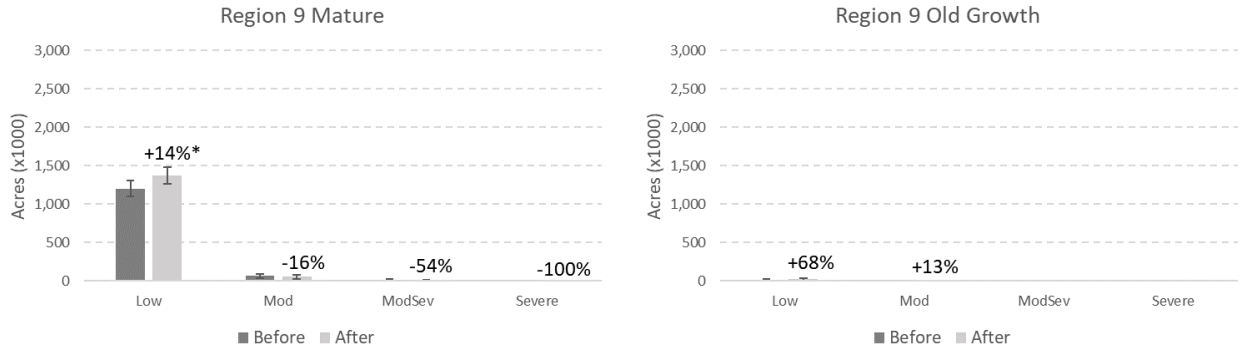

Figure A9.8.—Region 9 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after an insect/disease disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).

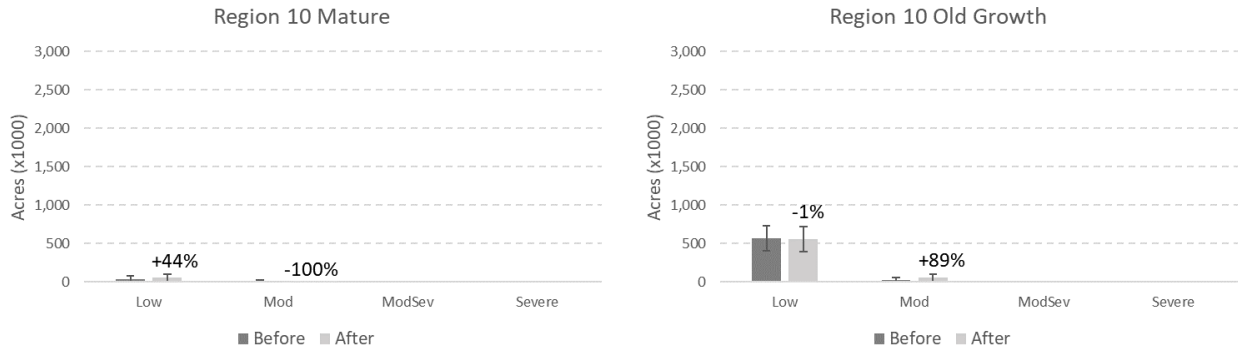

Figure A9.9.—Region 10 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after an insect/disease disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).

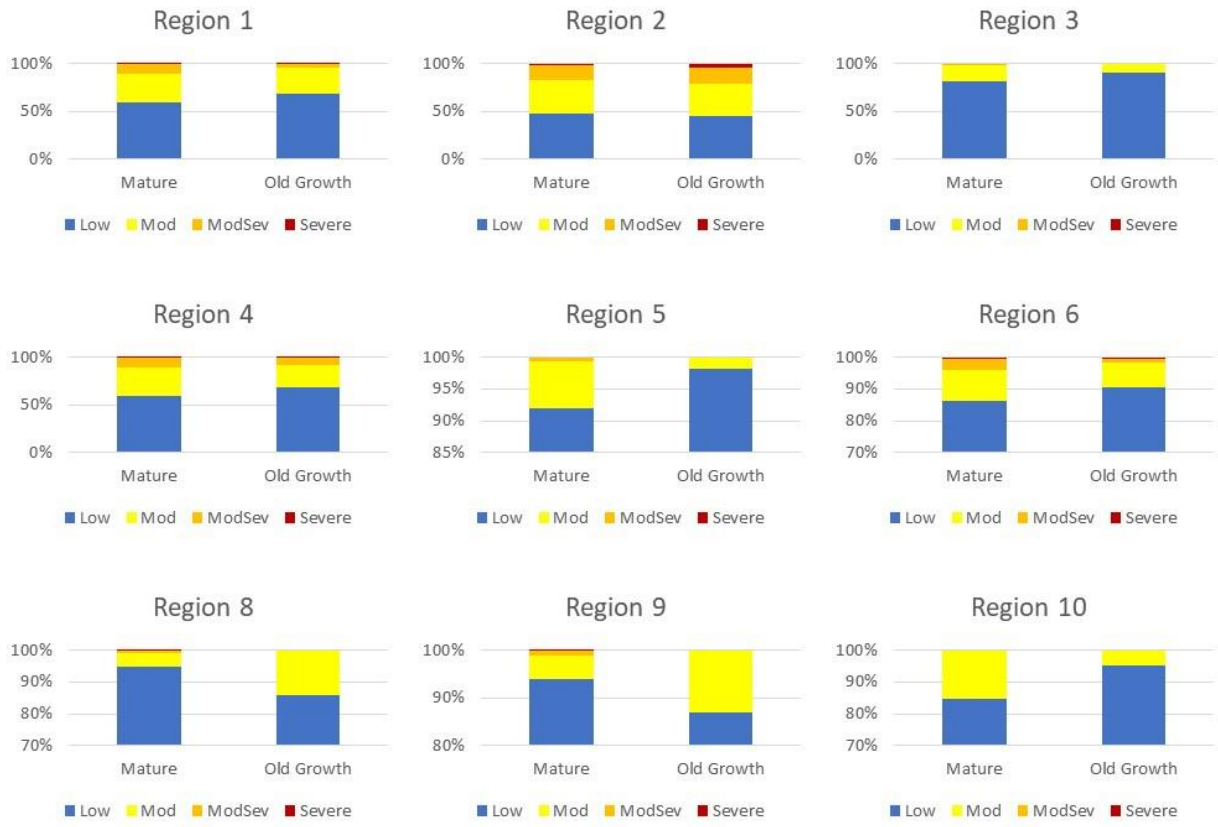

Figure A9.10.— Regional variations in insect/disease disturbance severity (basal area mortality) for mature and old-growth forests. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).

Appendix 10 – Regional Weather Summary

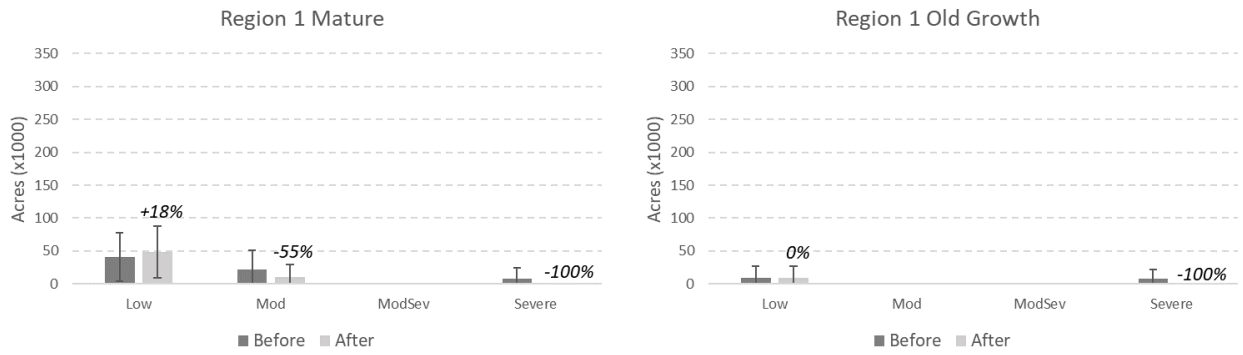

Figure A10.1.—Region 1 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after a weather disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).

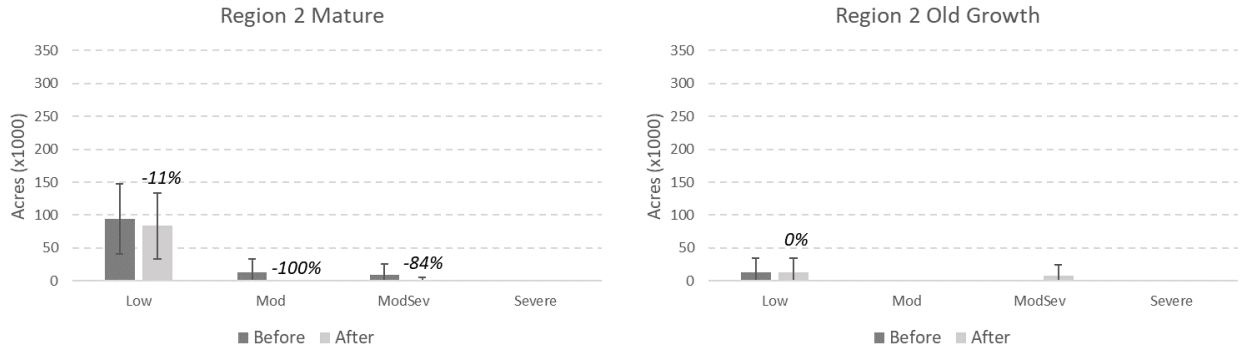

Figure A10.2.—Region 2 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after a weather disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).

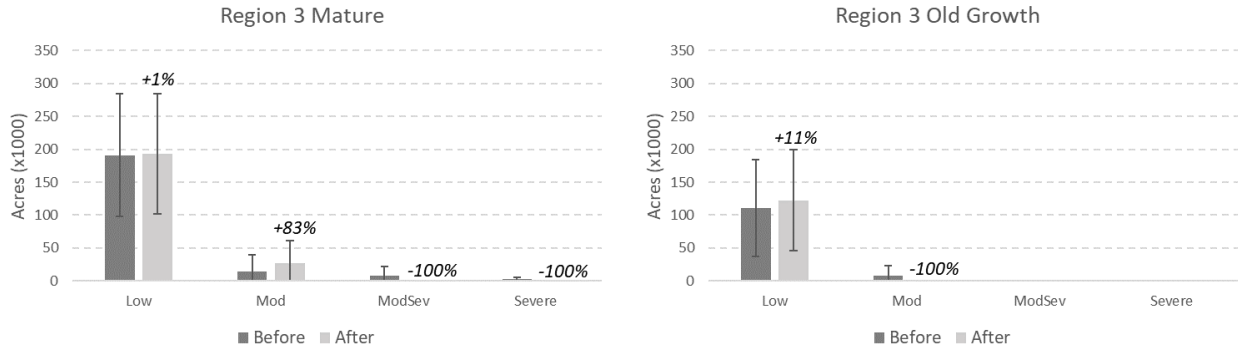

Figure A10.3.—Region 3 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after a weather disturbance. Asterisks (*) indicate net change was statistically significant Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).

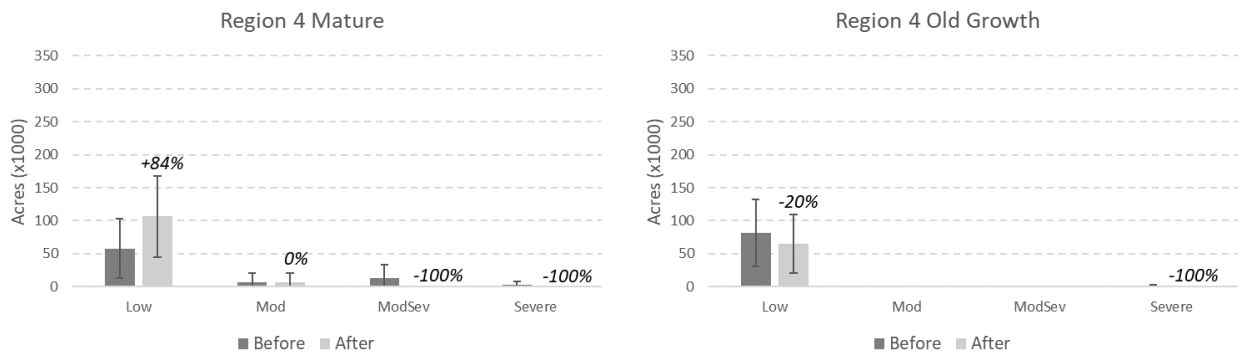

Figure A10.4.—Region 4 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after a weather disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).

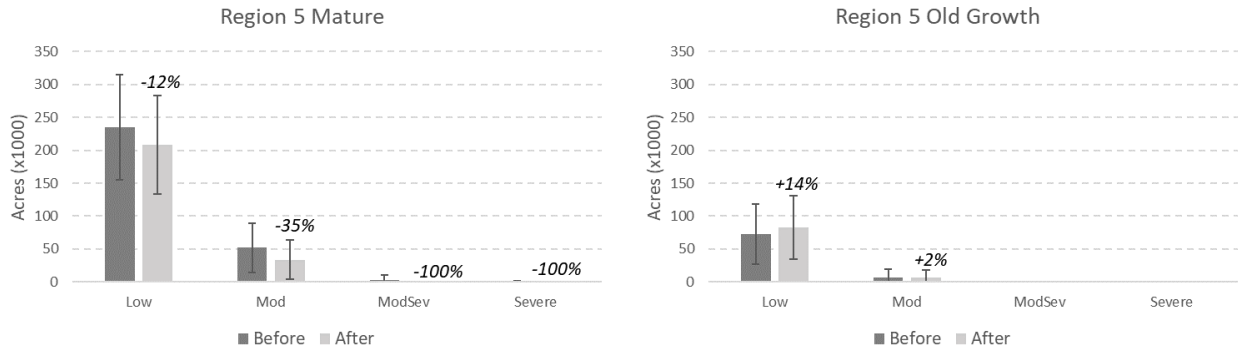

Figure A10.5.—Region 5 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after a weather disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).

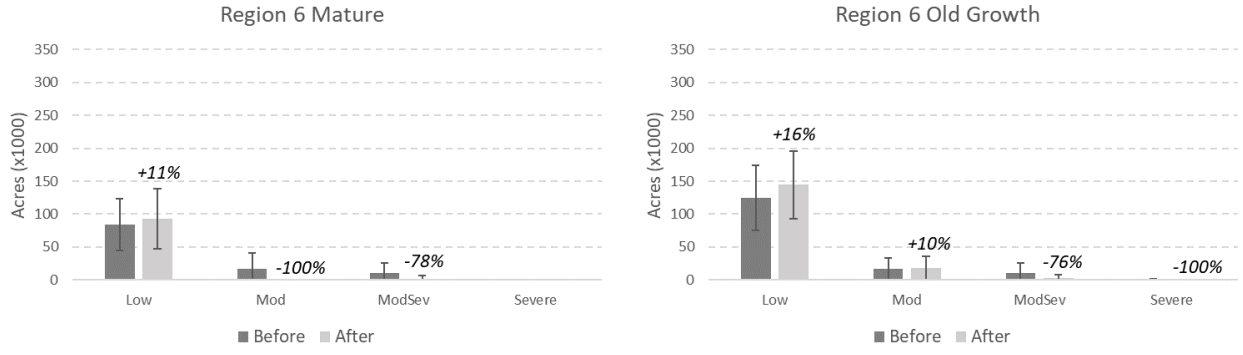

Figure A10.6.—Region 6 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after a weather disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).

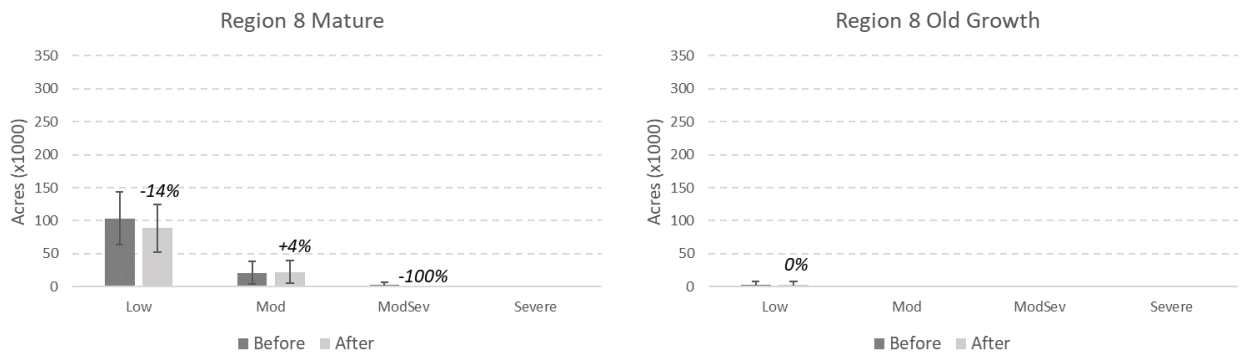

Figure A10.7.—Region 8 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after a weather disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).

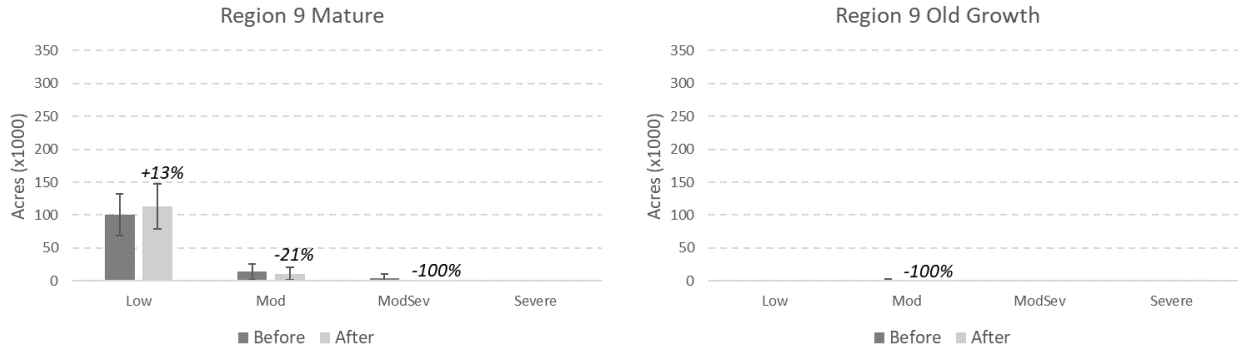

Figure A10.8.—Region 9 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after a weather disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).

Figure A10.9.—Region 10 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after a weather disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).

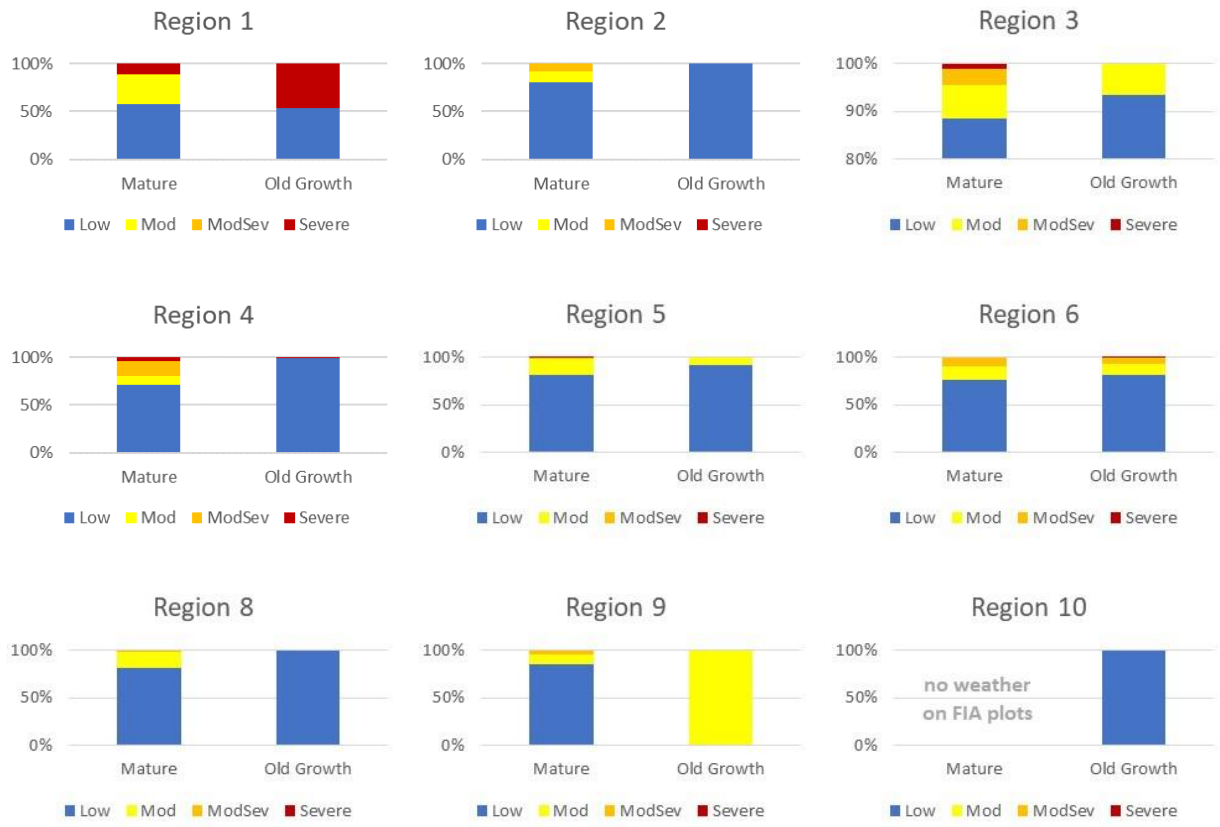

Figure A10.10.— Regional variations in weather disturbance severity (basal area mortality) for mature and old-growth forests. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality)..

Appendix 11 – Complex Perspectives on Tree Cutting

This appendix highlights the complex language used to describe tree cutting in land management and the associated range of perspectives expressed through that language.

Similar to ecological relationships between tree cutting and adverse outcomes in mature and old growth forests, social, cultural, and economic values interact with tree cutting in a complex way. Discussing the relationship between diverse values and tree cutting requires acknowledging the variety and complexity of terms used by different people and the potential miscommunication stemming from the language employed. Responses to questions posed during threat analysis engagement sessions illustrate the array of terms used to describe tree cutting (appendix 2). Engagement responses that mentioned what this threat analysis labeled 'tree cutting' differed among stakeholder groups (figure A11.1)

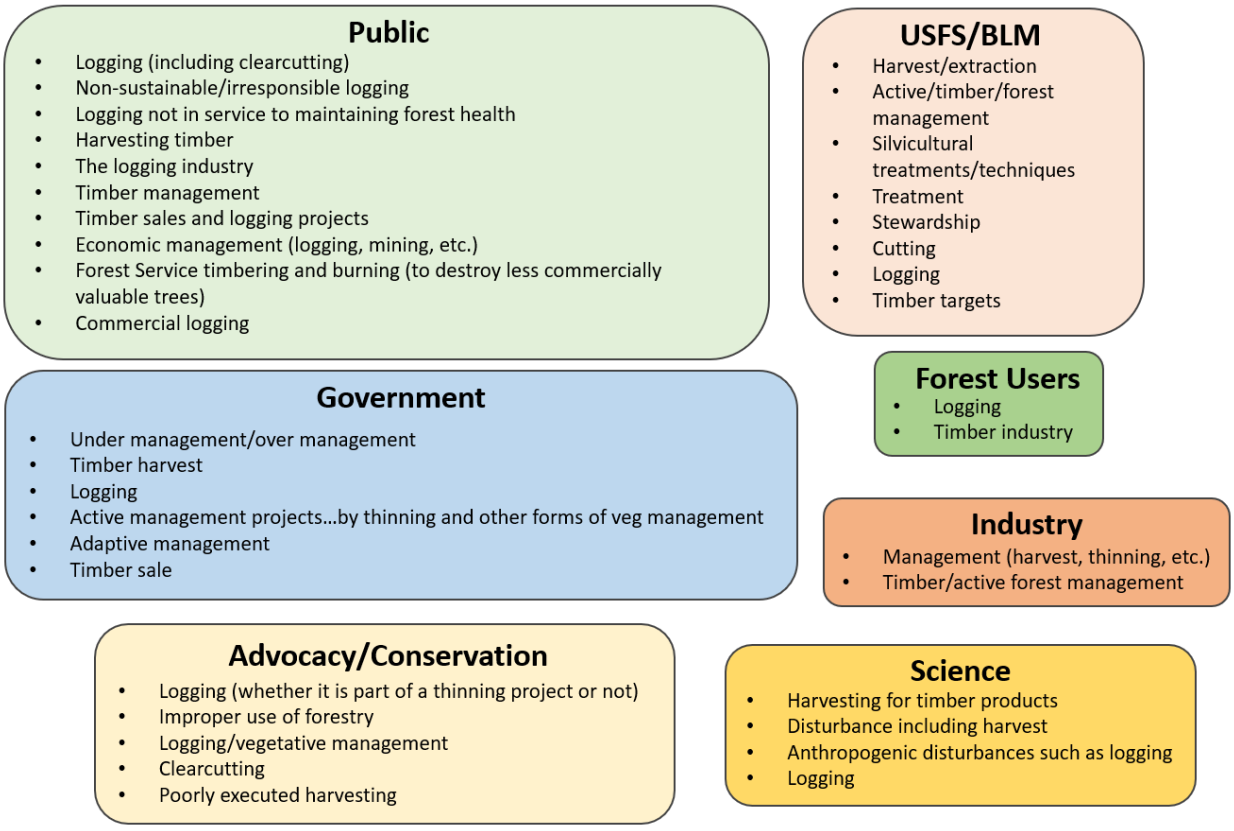

Figure A11.1.—Stakeholder responses to the term 'tree cutting' illustrate the complexity of perspectives on the subject.

Most groups used the term “logging”, though it was more common among some than others. Only one FS/BLM respondent used “logging”, while most other FS/BLM employees used “management”. The most important takeaway is that many terms are in use, and it is not always clear what people mean when they use one term or another. Indeed, a FS/BLM employee cited “common language and transparency” as a challenge to federal management and stewardship of MOG forests. Some employees feel the responsibility for addressing this could rest with the agency, as another employee stated the challenge is “lack of communication to our public of why we are managing our forested landscapes. We don’t provide the context of conservation outcomes that are important.”

Confusion and miscommunication may result in part from describing the process in different terms, but lack of public trust can also be a factor. Through engagement session feedback, some stakeholders and members of the public described tree cutting in ways that suggest they view it as a Forest Service ruse; the agency claims to be pursuing one set of objectives but in fact has others in mind. For example, one member of an advocacy group named logging as a threat “…either in the name of timber production or in the name of supposedly ameliorating the damage to MOG forests from climate change, insects, disease, drought, etc.” Another suggested it takes place “…under the cover of ‘ecological thinning’ or ‘community resiliency’…” Some members of the public took similar positions. One articulated “There are all too many fire management strategies that involve cutting down large (commercially valuable) trees with limited actual fire benefit – they’re logging disguised as fire management…”

The views expressed through these examples are not unanimous. Another advocacy group member stated “I think management is a very small concern. It is regulated. There is a public process, etc.” Some attendees teased out nuance in the process while bringing in political concerns. For example, “The FS may argue that it’s not in [the] business of logging older firsts [sic] but what if we get a trump 2.0 who targets unprotected MOG to bump up board feet. Additionally, the FS does log mature and that’s not necessarily a bad thing – maybe there’s too much in some places. That said, we may need a lot of mature in other places to reestablish old growth.”

Forest Service and BLM employees identified the complexity around tree cutting and the need to communicate with the public to acquire social license to perform management actions the agency deems necessary. When asked about challenges to management and stewardship of MOG forests, employees who attended engagement sessions in July 2023 wrote about issues regarding communication with the public, public perceptions, and social license. In fact, by a wide margin, this category garnered the largest number of responses in answer to this question. One pointed out that challenges to managing MOG include “…public perception of stewardship, esp. in dry or mixed forest types: treatment and burning as beneficial to restoring health vs. no-touch preferences (with perception of ‘logging’ being a threat to MOG, as it was historically)”. This statement also shows that the various values for which the agencies seek to manage are factors in the challenges of communicating with, and working with, a variety of stakeholder groups. A non-FS/BLM government employee also noted a challenge stemming from “… public misperceptions about government agency intentions.”

All told, the nuance and complexity of tree cutting and the language used to describe it can result in confusion when the terminology isn't commonly understood. Understanding requires unpacking terminology used, the nuances of goals and desired outcomes, and the range of both the perceived and actual extent and effects of tree cutting. The complexity of evaluating potential threats also stems from the multiple outcomes as tree cutting interfaces with human values and ecological outcomes: tree cutting can reduce certain social and cultural values or forest ecosystem services, while generating and maintaining other social and cultural benefits and ecosystem services, at the same time and in the same location.

Appendix 12 – Regional Tree Cutting Summary

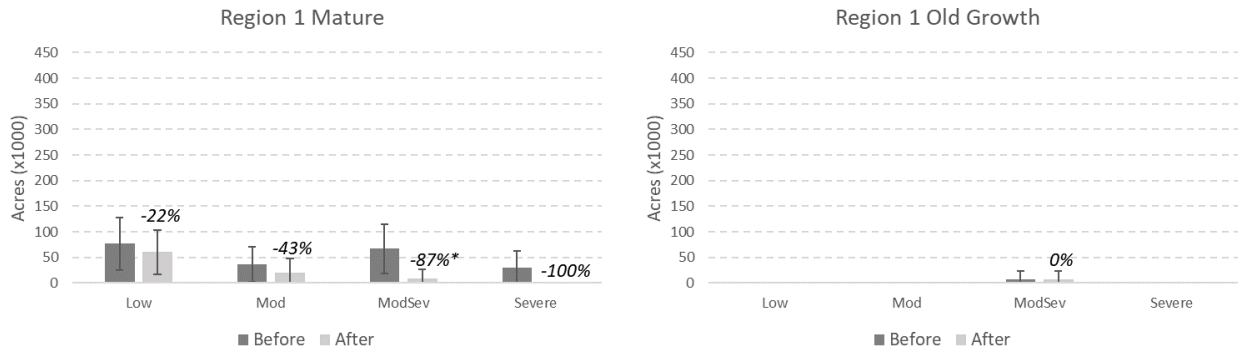

Figure A12.1.—Region 1 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after a tree cutting disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).

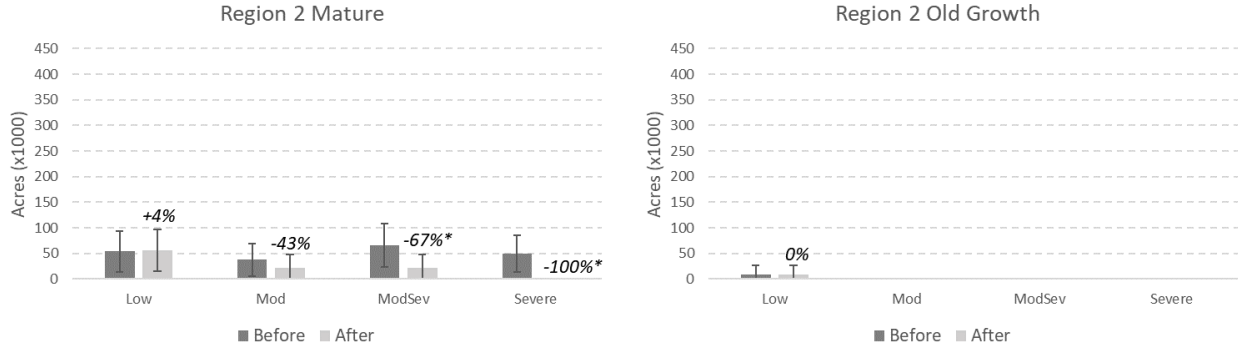

Figure A12.2.—Region 2 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after a tree cutting disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).

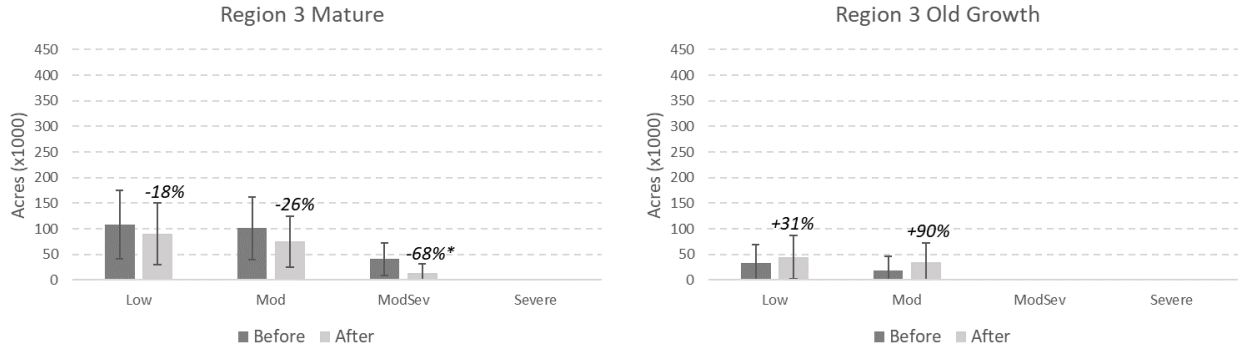

Figure A12.3.—Region 3 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after a tree cutting disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).

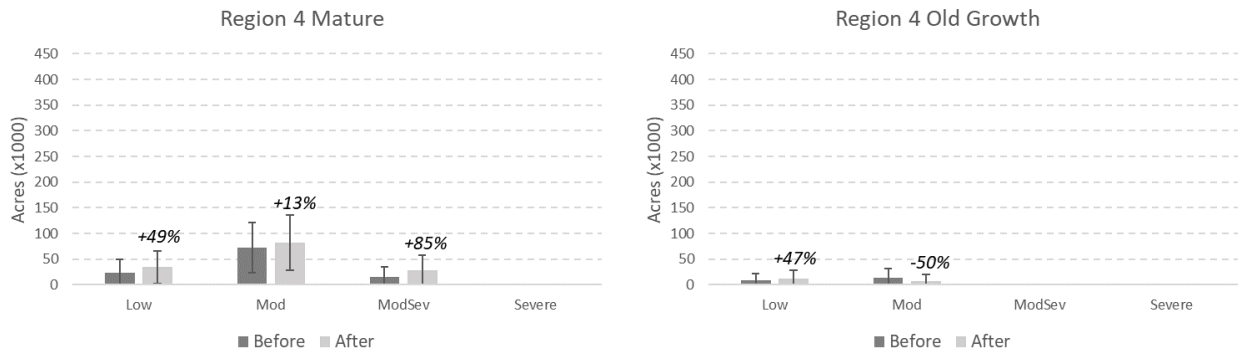

Figure A12.4.–Region 4 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after a tree cutting disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).

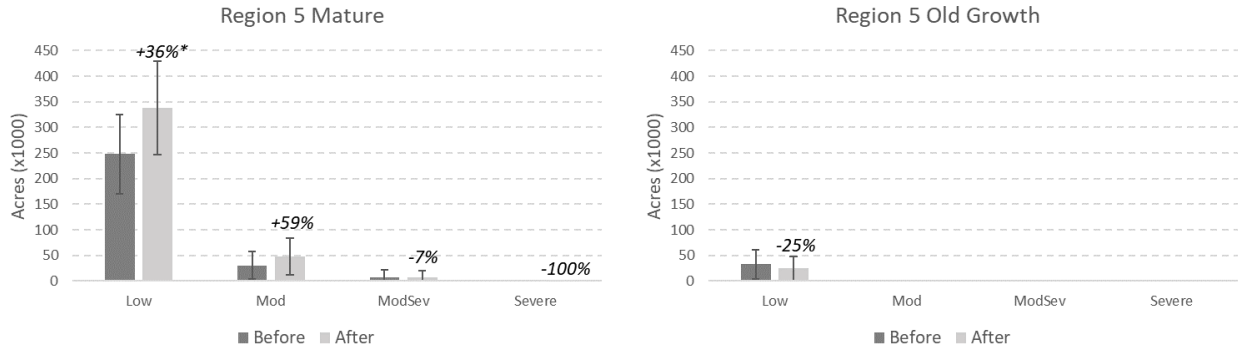

Figure A12.5.—Region 5 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after a tree cutting disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).

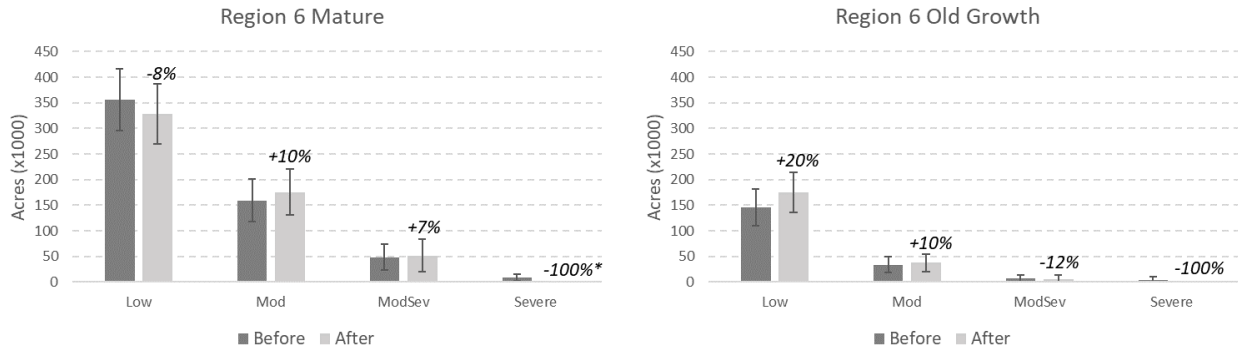

Figure A12.6.—Region 6 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after a tree cutting disturbance. Asterisks (*) indicate net change was statistically significant Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).

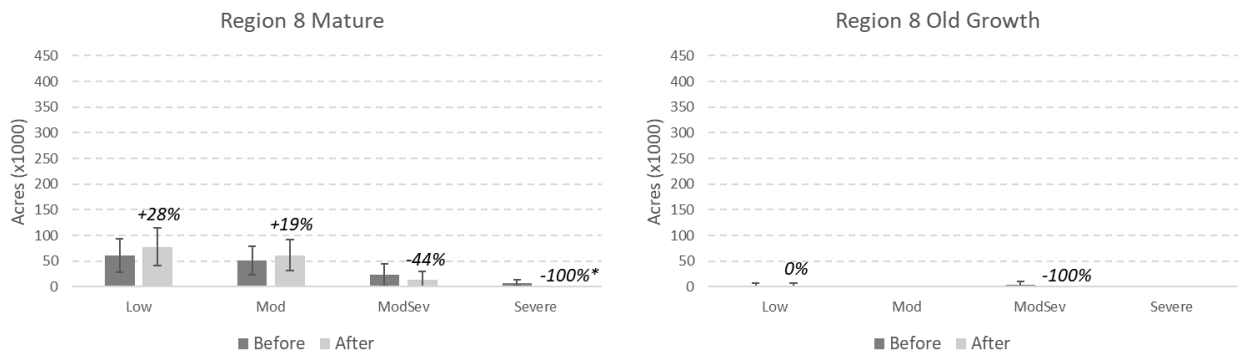

Figure A12.7.—Region 8 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after a tree cutting disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).

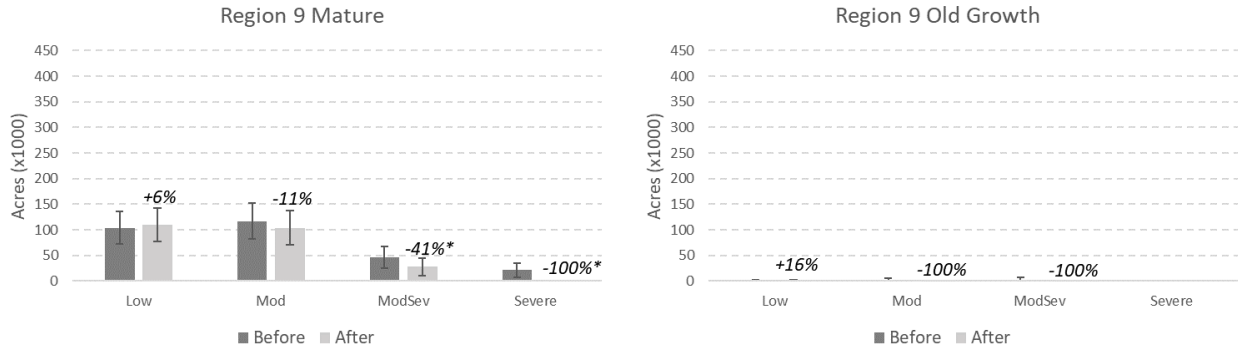

Figure A12.8.—Region 9 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after a tree cutting disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).

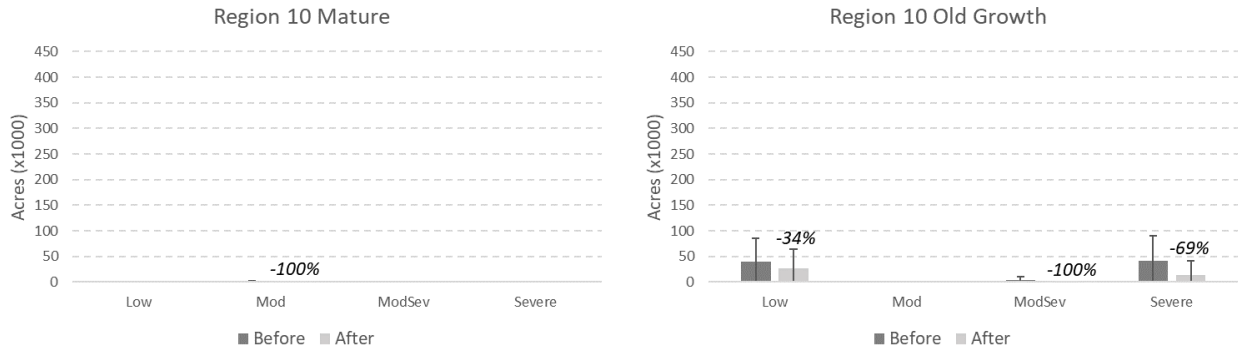

Figure A12.9.—Region 10 net changes in mature and old-growth forest acres (with 95-percent confidence intervals) before and after a tree cutting disturbance. Asterisks (*) indicate net change was statistically significant. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).

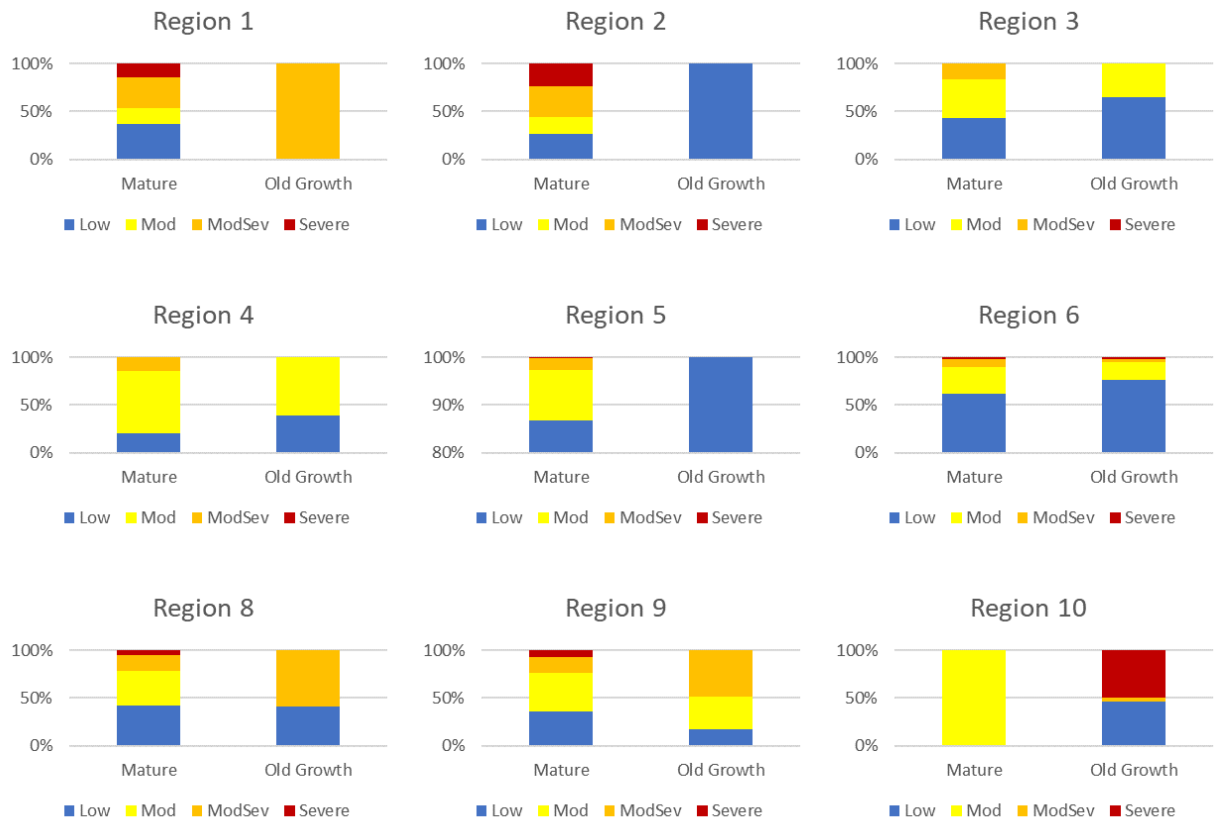

Figure A12.10.— Regional variations in tree cutting disturbance severity (basal area mortality) for mature and old-growth forests. Disturbance severity was classified as Low (<25% basal area mortality), Mod (25–60% basal area mortality), ModSev (60 –90% basal area mortality), or Severe (>90% basal area mortality).

Appendix 13 – Regional All Disturbances Summary

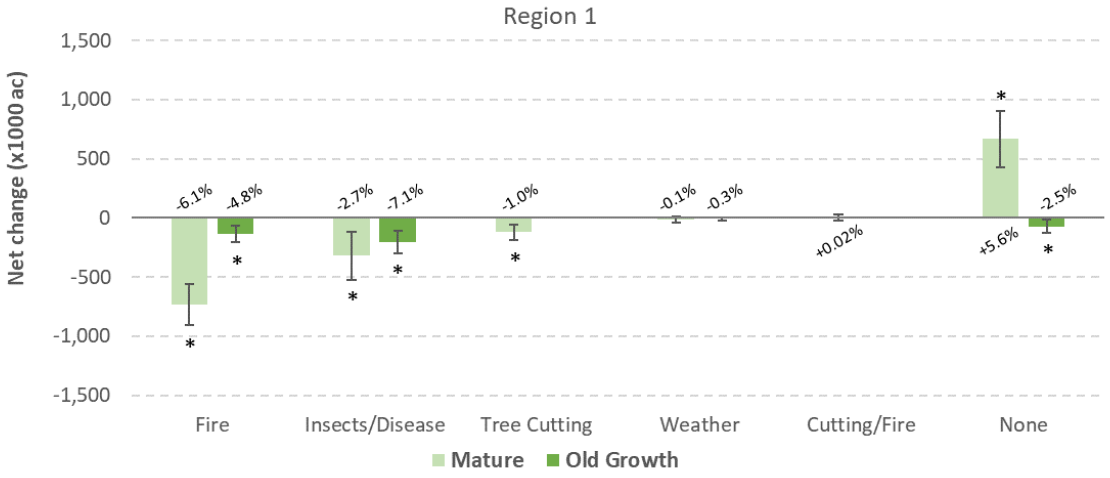

Figure A13.1.—Region 1 net changes (with 95-percent confidence intervals) to mature and old-growth forest acres based on remeasured Forest Inventory and Analysis (FIA) plots ordered (from left to right) by largest net losses to largest net gains. Percentages are mean net changes. Asterisks (*) indicate a statistically significant net change.

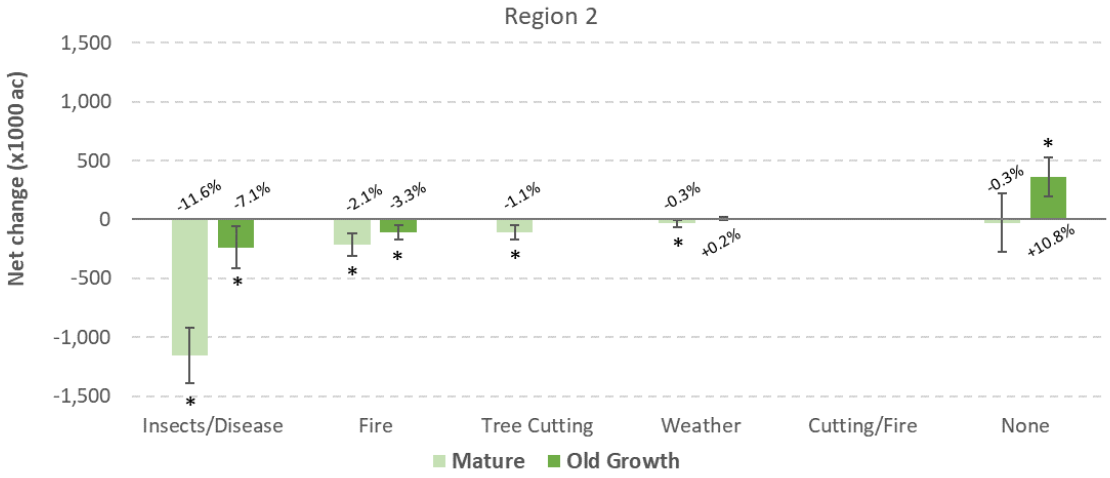

Figure A13.2.—Region 2 net changes (with 95-percent confidence intervals) to mature and old-growth forest acres based on remeasured Forest Inventory and Analysis (FIA) plots ordered (from left to right) by largest net losses to largest net gains. Percentages are mean net changes. Asterisks (*) indicate a statistically significant net change.

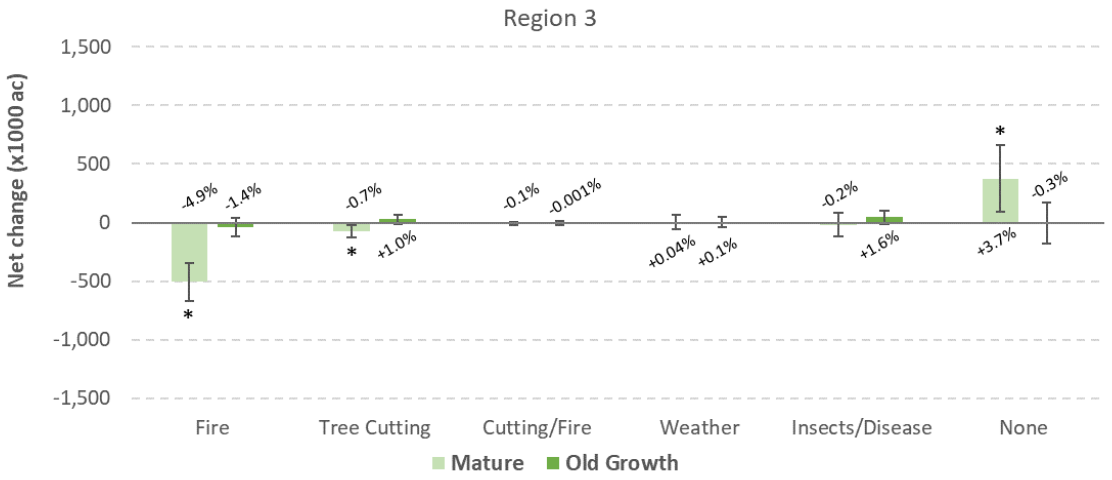

Figure A13.3.—Region 3 net changes (with 95-percent confidence intervals) to mature and old-growth forest acres based on remeasured Forest Inventory and Analysis (FIA) plots ordered (from left to right) by largest net losses to largest net gains. Percentages are mean net changes. Asterisks (*) indicate a statistically significant net change.

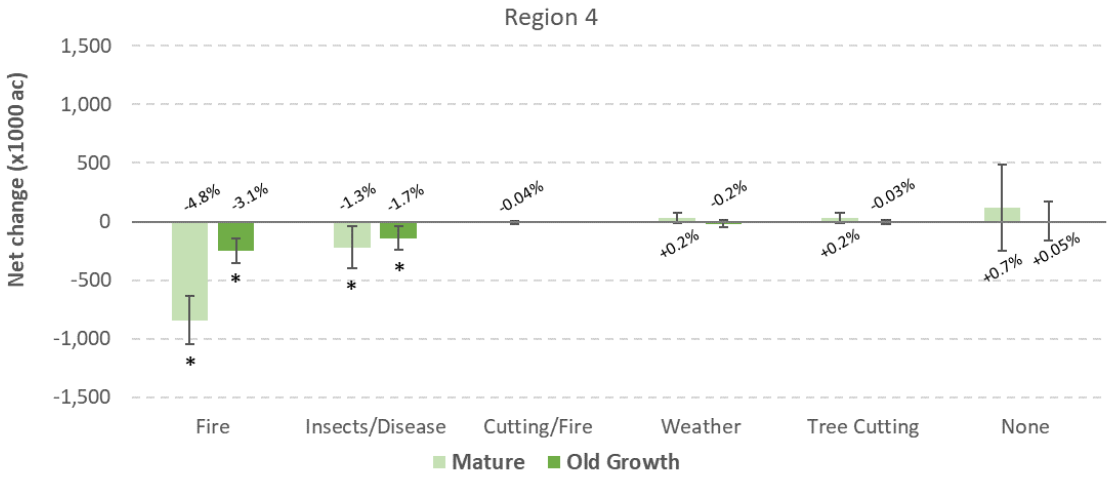

Figure A13.4.—Region 4 net changes (with 95-percent confidence intervals) to mature and old-growth forest acres based on remeasured Forest Inventory and Analysis (FIA) plots ordered (from left to right) by largest net losses to largest net gains. Percentages are mean net changes. Asterisks (*) indicate a statistically significant net change.

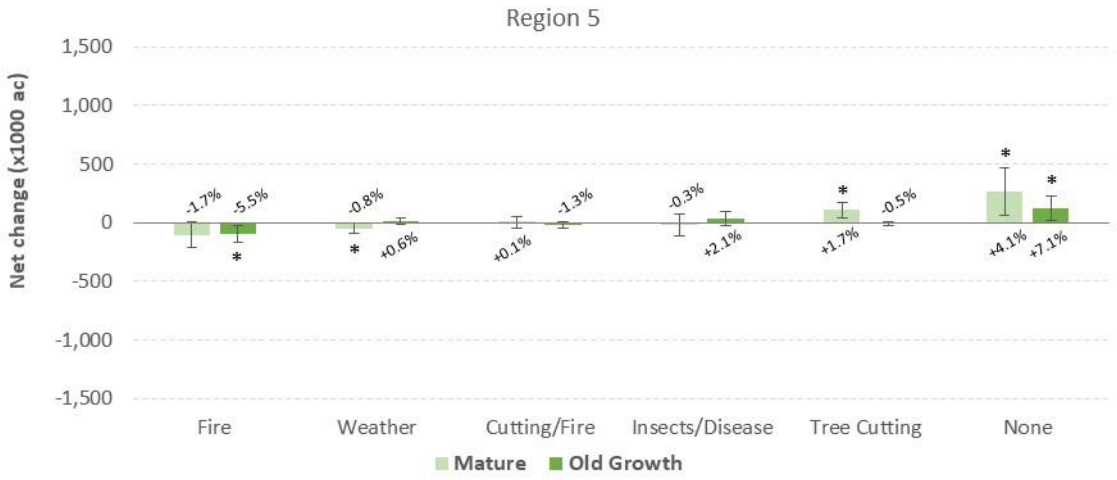

Figure A13.5.—Region 5 net changes (with 95-percent confidence intervals) to mature and old-growth forest acres based on remeasured Forest Inventory and Analysis (FIA) plots ordered (from left to right) by largest net losses to largest net gains. Percentages are mean net changes. Asterisks (*) indicate a statistically significant net change.

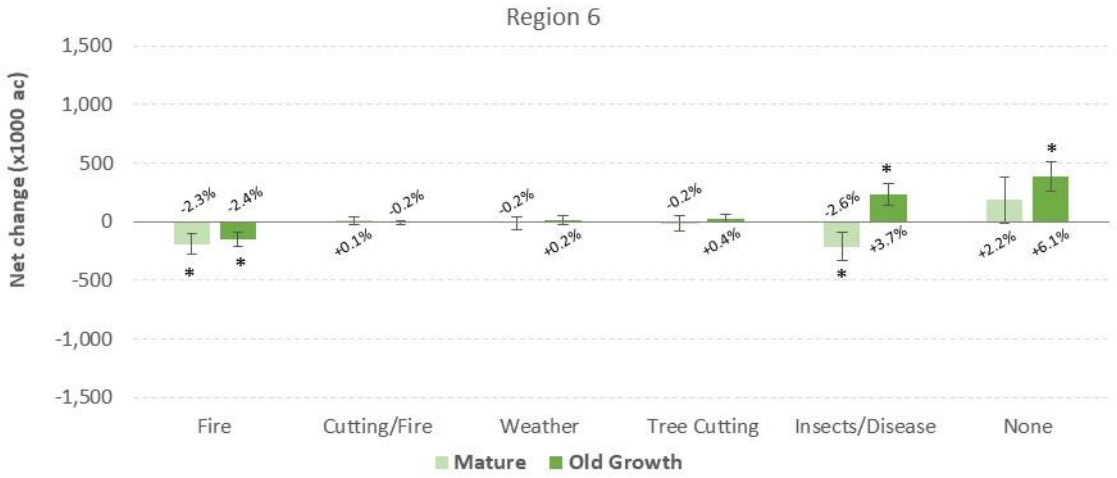

Figure A13.6.—Region 6 net changes (with 95-percent confidence intervals) to mature and old-growth forest acres based on remeasured Forest Inventory and Analysis (FIA) plots ordered (from left to right) by largest net losses to largest net gains. Percentages are mean net changes. Asterisks (*) indicate a statistically significant net change.

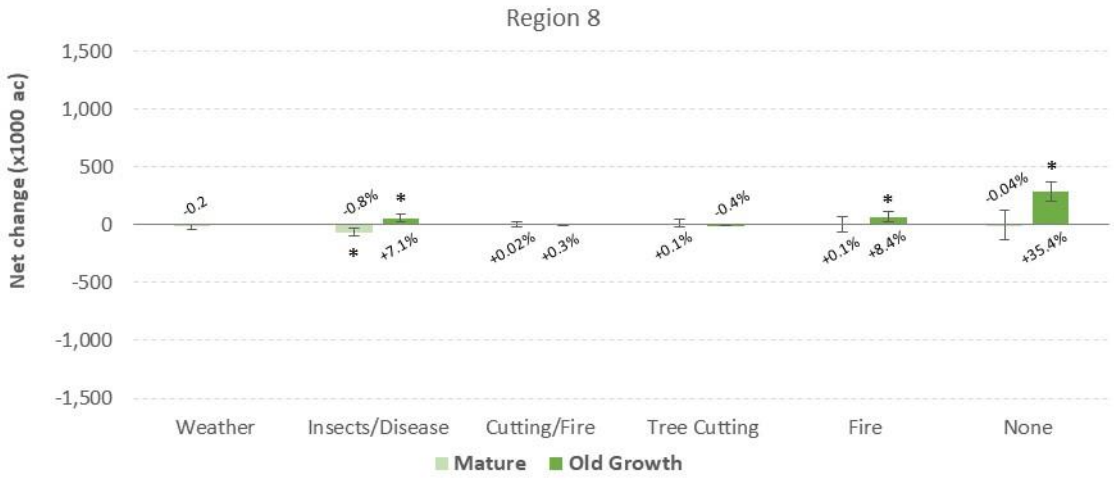

Figure A13.7.—Region 8 net changes (with 95-percent confidence intervals) to mature and old-growth forest acres based on remeasured Forest Inventory and Analysis (FIA) plots ordered (from left to right) by largest net losses to largest net gains. Percentages are mean net changes. Asterisks (*) indicate a statistically significant net change.

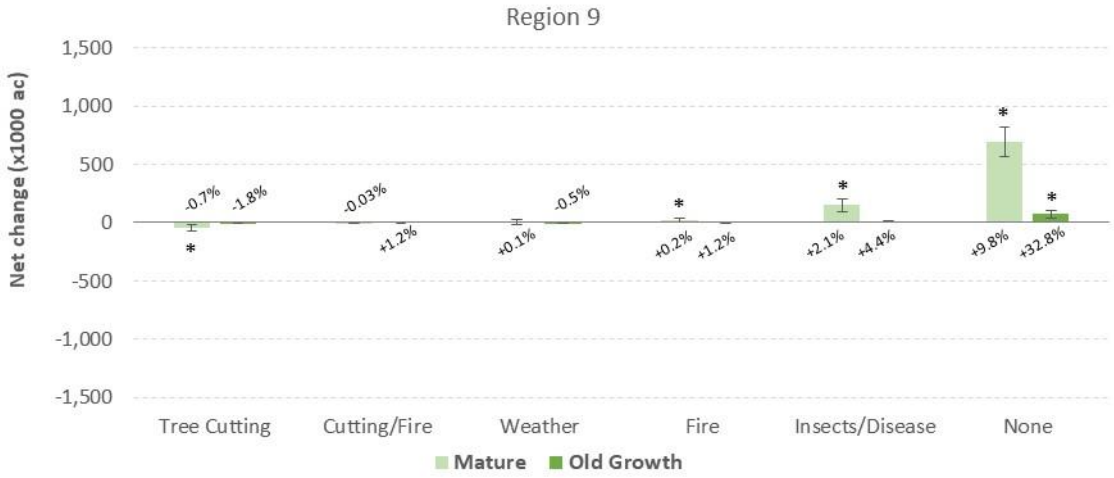

Figure A13.8.—Region 9 net changes (with 95-percent confidence intervals) to mature and old-growth forest acres based on remeasured Forest Inventory and Analysis (FIA) plots ordered (from left to right) by largest net losses to largest net gains. Percentages are mean net changes. Asterisks (*) indicate a statistically significant net change.

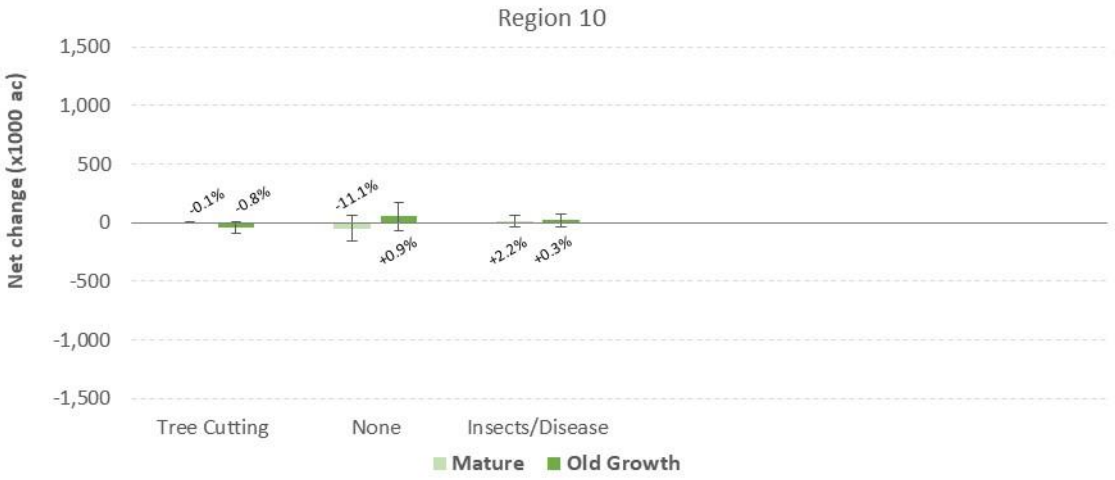

Figure A13.9.—Region 10 net changes (with 95-percent confidence intervals) to mature and old-growth forest acres based on remeasured Forest Inventory and Analysis (FIA) plots ordered (from left to right) by largest net losses to largest net gains. Percentages are mean net changes. Asterisks (*) indicate a statistically significant net change.

Appendix 14 – Mature and Old Growth Climate Change Vulnerability Assessment Synthesis

Overview

The ecological and social significance of mature and old-growth forests has made them a priority for conservation on public lands. This was recently institutionalized by Executive Order 14072, Section 2(b) and the report "Mature and Old-Growth Forests: Definition, Identification, and Initial Inventory on Lands Managed by the Forest Service and Bureau of Land Management". Although MOG forests have been protected from harvest in wilderness areas and other protected lands for many years, there is now increased urgency to increase the extent of MOG forests on other federal lands that are typically managed with multiple resource objectives. Restoration and long-term sustainable management of MOG are currently a major emphasis on Forest Service and Bureau of Land Management lands throughout the nation.

Climate change is a relatively new challenge for the conservation of MOG forests. Tree species that are present in current forest landscapes have persisted through a broad range of climatic variability at annual to millennial scales, as well as extensive timber harvesting and other human activities. However, recent human-caused climate change, and associated extreme weather events and disturbances, are creating conditions that increase stress for many species and perhaps opportunities for others. Climate change is superimposed on an existing template of diverse stress complexes that include biological components (e.g., insects, diseases) and human factors (e.g., land-use change, air pollution).

The effects of climate change on forest ecosystems, including MOG forests, will be mediated primarily through extreme weather events and disturbances that are provoked by extreme weather and climate. This includes drought, insect outbreaks, pathogen epidemics, increased frequency and extent of wildfire, and increased flooding. These disturbances test the tolerance levels of trees, and following the disturbance, set the stage for a competition among trees that will determine which species will persist in a warmer climate with more frequent disturbances. Chronic climate-related factors (e.g., temperature increase) affect tree regeneration, physiology, and growth at longer time scales. This sharpens the competition among tree species, tests their adaptive capacity, and ultimately affects their distribution and abundance across large landscapes.

In this document, we assess the potential effects of climate change on MOG forests in the western continental United States, divided in sections for the six Forest Service Regions within this geographic area. Inferences are based on published climate change vulnerability assessments and other scientific literature available for this area; projections should be relevant through at least the end of the 21st century. Each section describes climate change effects by "forest types," which are intended to characterize assemblages of common species in general geographic locations. Effects on existing MOG forests are discussed explicitly, with additional discussion on long-term effects on forest dynamics and regeneration to support inferences about the potential

for MOG forests to persist within each region. This longer view is needed to inform conservation of MOG forests and sustainable resource management in general.

Intermountain Region

Higher temperature is expected to cause a gradual change in the distribution and abundance of dominant forest species in the Intermountain Region. Increased ecological disturbance, driven by higher temperatures, is expected to cause near-term effects on forest and age-class structure, and will facilitate long-term changes in dominant vegetation. In forest ecosystems, native and non-native insects are expected to be significant stressors in a warmer climate; in fact, this appears to already be occurring. An increase in the frequency and extent of wildfire will be a significant stressor in all forest types, especially where fuel loadings are high. Nonnative plant species will continue to expand, potentially displacing native species and altering fire regimes. A combination of these and other stressors (stress complexes), exacerbated by climate, may accelerate the rate of change in forest ecosystems, reducing productivity and carbon storage.

At low elevations, MOG forests are relatively uncommon because of a long history of logging, although some MOG forests can still be found in wilderness areas and other protected lands. At high elevations, MOG forests are more common because they are less accessible and were less affected by logging. A notable exception is lodgepole pine and spruce forests where beetles have caused large areas of mortality. Effects of climate change are summarized for five forest types:

- Subalpine forest
- Mixed conifer forest
- Aspen forest
- Montane pine forest
- Riparian forest

Subalpine Forest

Subalpine forests dominated by whitebark pine will be highly vulnerable in a warmer climate, primarily because this species is already subjected to considerable stress from white pine blister rust and mountain pine beetles. As a result, populations are in decline and reproductive capacity is limited, even when germination conditions are suitable. In areas where wildfire has been excluded for many decades, elevated fuel loadings may create high-intensity fires that lead to mortality of MOG trees. Ongoing decline in whitebark pine has cascading effects on other species that eat its seeds, especially Clark’s nutcracker. Subalpine forests in which bristlecone pine is a major component are mostly in dry locations that could become increasingly stressed by low soil moisture, which would reduce growth.

Other subalpine forests are expected to be moderately affected by a warmer climate. Limber pine, subalpine fir, Engelmann spruce, and white fir may all have increased growth in the upper subalpine zone because of a longer, snow-free growing season. These species may migrate to

higher elevations where conditions are suitable, although this would be a slow process over many decades. If wildfire increases in the subalpine zone, especially where it has been excluded in the past, crown fires may be prevalent, quickly eliminating MOG trees across the landscape. Limber pine is stressed by mountain pine beetles and white pine blister rust.

Spruce-fir forests will be moderately vulnerable to a warmer climate. Subalpine fir, Engelmann spruce, and blue spruce may all have increased growth in the upper subalpine zone because of a longer snow-free growing season, so overall productivity could increase. These species may migrate to higher elevations where conditions are suitable, although this would be a slow process over decades to centuries. If wildfire increases in the subalpine zone, especially where it has been excluded in the past, crown fires may be prevalent, quickly eliminating MOG stands across the landscape. Spruce beetles and spruce budworms are significant stressors, especially in dense, older forests.

Bark beetle outbreaks in Engelmann spruce and lodgepole pine are often severe and can accelerate succession in areas of high tree mortality. Most subalpine species are fire intolerant, but because most lodgepole pine populations have serotinous cones and the potential for dense regeneration, it is likely to persist in high-elevation landscapes. Quaking aspen in subalpine forests will be minimally affected by a warmer climate, especially compared to aspen at lower elevations. Where Douglas-fir is a seral species, it could increase in distribution and abundance where sufficient soil water is available. In addition, Douglas-fir is more fire tolerant than its associates, so it may become more common and move upslope as wildfire increases.

Mixed Conifer Forest

The composition of mesic mixed conifer forest varies across the region, with site conditions and species assemblages determining vulnerability to climate change. In general, MOG forests will become increasingly susceptible to wildfire, especially where fire has been excluded for many decades and fuel loads are elevated. Firs and lodgepole pine are subject to high mortality from intense fires. As snowpack declines and summer temperature increases, growth and productivity will probably decrease, except on north aspects.

Douglas-fir and ponderosa pine have high fire tolerance and can survive mixed-severity fires. Therefore, if wildfire extent and intensity increase in the future, these species will become more common, and other species in MOG stands will become less common. Douglas-fir and ponderosa pine tolerate dry soils, so they are likely to persist across the landscape, but their growth rates will likely decrease. Lodgepole pine and quaking aspen, which are also common, both respond to wildfire with rapid, abundant regeneration and are expected to persist across the landscape, possibly with increased stress from insects and pathogens.

Dry mixed conifer forests are located in lower-elevation montane sites, often on steep slopes and shallow soils. This forest type contains some of the most drought-tolerant species in the region. Common seral species include ponderosa pine, which is fire tolerant and regenerates well after fire, and quaking aspen, which sprouts heavily and reproduces by seed after fire. The woodland species curl-leaf mountain mahogany, Gambel oak, and bigtooth maple are drought tolerant, and

the latter two sprout vigorously after fire. Therefore, a major component of dry mixed conifer forest should be able to cope with drier soils and increased wildfire.

Two-needle pinyon and single-leaf pinyon are drought tolerant, and although intense fire typically kills them, they can usually regenerate successfully if competition is minimal. Singleleaf pinyon at its lowest elevational extent in northern New Mexico has experienced high mortality from prolonged drought and pinyon engraver and Ips beetles during recent decades, which suggests that this species will be susceptible to increasing drought in the future. Limber pine, which is considered late seral in these forests, is drought tolerant but may be stressed by mountain pine beetle, white pine blister rust, and increasing (usually fatal) wildfire.

The growth of Douglas-fir and white fir will likely decrease in a warmer climate, and although Douglas-fir has relatively high fire tolerance, white fir tolerates fire only when it has large diameter and thick bark. In a warmer climate with more wildfire, it will be increasingly difficult for these conifer species to compete with early-seral and woodland species that are more tolerant of drought and fire. Therefore, it is likely that early-seral species will become more dominant in the future, and MOG stands will become less common and perhaps confined to north aspects and valley bottoms.

Quaking Aspen Forest

Quaking aspen is often found in combination with other conifer and woodland species. Response to climate change will depend on associated species, ranging from high to low elevation, and from north to south aspects. Although aspen is often considered an early-seral species following wildfire, it can persist for many decades in some forests, where productivity is low and conifer species do not compete well. Large stands dominated by MOG aspen and younger trees are found at higher elevations of the subalpine zone, even in the absence of wildfire. Increased wildfire frequency and extent will be a primary factor determining future composition and structure of aspen-mixed conifer and persistent aspen forests.

Late seral species (firs, Engelmann spruce) in MOG stands of this forest type are readily killed by fire. If wildfire reaches into the subalpine zone, it is likely that mature spruce-fir forests will become less common or will persist only on north slopes and in valley bottoms. Therefore, aspen has the potential to attain increasing dominance because of its ability to sprout and establish by seed after fire. This will also be true at lower elevations, where ponderosa pine can readily survive intense fires, and other species such as aspen and Gambel oak sprout vigorously after fire. Productivity in these systems will probably be lower in a warmer climate with more fire. But the more fire-tolerant species will persist, especially in drier locations, where they can outcompete species that are susceptible to drought and fire.

Montane Pine Forest

Ponderosa pine is a dominant species in drier montane locations throughout much of the region. Several other conifer species (Douglas-fir, limber pine, Great Basin bristlecone pine, white fir) are included in this forest type but are rarely as abundant as ponderosa pine, except in wetter locations (north aspects, valley bottoms). Ponderosa pine is persistent in these forests because it

is drought tolerant and fire tolerant, allowing it to develop into MOG stands in some places. Consistently drier soils will cause this species to grow slower, but mortality may be rare unless drought lasts for several consecutive years and biotic agents cause additional stress.

The expected increase in frequency and extent of wildfire in a warmer climate will favor ponderosa pine over its less fire-tolerant competitors, thus ensuring dominance in most forests. But limber pine and bristlecone pine, species that are often in MOG stands, will probably persist at higher elevations where fuel loads are low. An exception might be in areas where fire exclusion has increased stand density and fuel loads conducive to crown fires, but even then, regeneration of ponderosa pine will probably be sufficient to maintain dominance after fire. If bark beetles become more prevalent in a warmer climate, they could increase stress and mortality in pine species, especially during drought periods.

Riparian Forest

Riparian forests are distributed throughout the region, adjacent to lakes, streams, seeps, springs, and high-water tables. Vegetation is diverse, including a broad range of conifer and hardwood species. Historically, wildfire has infrequently burned into riparian areas, making it possible for MOG stands to develop in some locations. Some of these species occur only in riparian systems, providing habitat for many animal species. In some drier locations, nonnative saltcedar and Russian olive reduce the available groundwater, displacing native species and creating what could be considered undesirable MOG stands.

Riparian systems will be vulnerable in a warmer climate because they depend on a reliable water supply. Higher temperatures will accelerate evapotranspiration as soils dry faster and as vegetation takes up water earlier and faster during the growing season. Surface and subsurface water flows will decrease if snowpack decreases and melts earlier, precluding recharge during dry summers. This will alter vegetation dominance to species that are more tolerant of seasonal drought, including ponderosa pine and other deep-rooted conifers in some places. Hardwood species that rely on periodic high water levels for regeneration could become less common. Riparian forests associated with small or transient water sources (e.g., springs) will be more susceptible than forests near large water sources (e.g., rivers). Low-elevation riparian forests near small water sources will be more susceptible than high-elevation forests where snowpack is retained into spring or early summer.

Northern Region

Increasing air temperature, through its influence on soil moisture, is expected to cause gradual changes in the abundance and distribution of tree species throughout the Northern Rocky Mountains, with drought-tolerant species becoming more competitive. The earliest changes will be at ecotones between lifeforms (e.g., upper and lower treelines). Ecological disturbance, including wildfire and insect outbreaks, will be a primary facilitator of vegetation change, and future forest landscapes may be dominated by younger age classes and smaller trees. High-elevation forests will experience declines in snowpack and longer growing seasons and are especially vulnerable to increased disturbance frequency. Increased abundance and distribution

of nonnative species, as well as the legacy of past land uses, create additional stress for regeneration of native forest species.

At low elevations, MOG forests are relatively uncommon because of a long history of logging, although some MOG forests can still be found in wilderness areas and other protected lands. At high elevations, MOG forests are more common because they are less accessible and were less affected by logging. A notable exception is lodgepole pine forests in which mountain pine beetles have caused large areas of mortality over the past 30 years. The effects of climate change are summarized for five forest types:

- Dry ponderosa pine/Douglas-fir forest
- Western larch mixed mesic forest
- Mixed mesic western white pine, western redcedar, western hemlock, and grand fir forest
- Lodgepole pine mixed subalpine forest
- Whitebark pine mixed upper subalpine forest

Dry Ponderosa Pine/Douglas-fir Forest

Dry ponderosa pine and Douglas-fir forests are found at lower elevations in some of the driest locations in the Northern Rockies. They are often in the foothills of mountain ranges and in flatlands bordering grasslands and shrublands. Historically, frequent low-intensity wildfires often maintained pure to mixed ponderosa pine woodlands and savannas. However, fire exclusion has led to increased tree density and abundance of Douglas-fir, making these forests susceptible to high-severity fire.

A hotter, drier climate may reduce the range of this forest type in some parts of its current range. Although MOG ponderosa pines are typically tolerant of drought, increased frequency and magnitude of droughts may, at a minimum, increase stress, thus decreasing tree vigor. This will in turn increase susceptibility to western pine beetles and mountain pine beetles, which can ultimately kill the trees. However, as drought increases, younger stands may expand into the mixed mesic forest type, especially on south slopes and other dry sites. The dry ponderosa pine/Douglas-fir forest type will probably be dynamic in the future, with many current forests seeing losses in Douglas-fir balanced by gains in ponderosa pine.

Fire exclusion for many decades in this forest type has increased stem densities and fuel loadings. This creates a higher likelihood of high-severity crown fires that can kill many MOG trees across the landscape. In addition, regeneration may be limited and/or slow because of loss of seed source, limited soil moisture, and high surface temperature.

Western Larch Mixed Mesic Forest

Western larch mixed mesic forests are located primarily at lower elevations in the northwestern portion of the region. They consist of a patchy mixture of western larch, ponderosa pine, lodgepole pine, Douglas-fir, and Engelmann spruce. Because these species have different tolerances for low soil moisture, they tend to be differentially distributed according to

topographic position. Larch is less common than it was historically (when it was maintained by wildfire) because of selective logging of this species, although planting of larch has increased in recent decades.

These forests evolved under a mixed-severity fire regime, although high-severity fire was more common on moist and cool sites, producing large burn patches, often with legacy western larch. Fire exclusion has advanced succession, with larch being replaced with mixed stands of lodgepole pine, Douglas-fir, and grand fir in many areas. The increased density of many of these forests puts them at risk to high-severity fire.

Western larch mixed mesic forests have undergone dynamic change over the past century and will continue to do so with the added influence of climate change. Fire exclusion is expected to continue to reduce western larch and increase the more shade-tolerant Douglas-fir, grand fir, and subalpine fir in some locations. Additional accumulation of surface and canopy fuels, combined with increased fire danger due to climate change, will make MOG trees in these forests susceptible to high-severity fire. In addition, western larch may transition to more northerly aspects where soils retain moisture during the growing season.

Some attributes of this cover type may make it more resilient to climate change in the future. Western larch is not as susceptible to the insects and diseases that affect other species, and it is the most fire-tolerant conifer species in western North America. Stands and landscapes with conditions that are within the historical range of variability are more likely to maintain resilience to climate change.

Mixed Mesic Western White Pine-Western Redcedar-Western Hemlock-Grand Fir Forest

Moist forests within the Northern Rockies are influenced by a maritime climate with wet winters and dry summers. Complex topography, microclimate, soil conditions, and various disturbances create vegetative mosaics in which abundance and distribution of dominant species differ considerably. Up to 10 different tree species can occupy a given stand, including ponderosa pine, western larch, Douglas-fir, grand fir, western white pine, western redcedar, western hemlock, lodgepole pine, and Engelmann spruce.

Natural disturbances (snow, ice, insects, disease, wildfire) create heterogeneity in patch sizes, forest structures, and composition. Native insects (e.g., bark beetles) and diseases (e.g., Armillaria root rot, dwarf mistletoes) infect and kill old or stressed individuals and tend to increase spatial diversity in forest stands. A mixed-severity fire regime also creates a mosaic of forest compositions and structures. White pine blister rust has killed a large portion of western white pines that were not logged. Timber harvest has removed most of the large ponderosa pine and western larch, which are early seral and fire tolerant.

Douglas-fir and grand fir regenerated aggressively in response to historical logging and fire exclusion. In addition, fire exclusion has prevented the creation of canopy openings and seedbeds for regeneration of pine and larch. Now, when wildfires occur, surface organic layers are consumed, decreasing the nutrition and microbial processes that sustain these forests.

If future moisture regimes no longer support the current distribution of western hemlock, the remaining species that thrive on the upland western redcedar habitat types are likely to become dominant. In addition, increasing fire danger in combination with elevated fuel loadings will facilitate more high-severity wildfires that can kill large trees in MOG stands. The exact nature of altered wildfire and other disturbance changes (intensity, extent, and return interval) will influence the distribution and abundance of species at all spatial scales.

Lodgepole Pine Mixed Subalpine Forest

This forest type is broadly distributed in the Northern Rockies, with vast subalpine areas dominated by even-aged and multi-aged stands of lodgepole pine, mixed with subalpine fir and quaking aspen. Although trees are smaller than in lower-elevation forests, MOG stands are extensive. Lodgepole pine forests are typically found at higher elevations in dry, cold environments. Aspen, which is often associated with wetter sites sprouts vigorously after wildfire, which limits dense regeneration of subalpine fir. Although subalpine fir has probably increased because of fire exclusion, most of this cover type is (or was recently) dominated by MOG lodgepole pine. Mountain pine beetles have killed large portions of these MOG forests in many parts of the region.

Subalpine forests in the Northern Rockies evolved with high-severity and mixed-severity fire regimes. Mixed-severity fire regimes were common in central Montana on flatter slope positions and produced a diverse pattern of patches of different ages and tree sizes with stand-replacing fire-return intervals of 100–500 years. The interaction of insects and wildfire also affects stand dynamics. For example, stands reaching 60–80 years often suffered mortality from mountain pine beetles, creating snags and down fuel.

This interaction between insects and fire could be further influenced by the effects of a warmer climate and drought on both disturbances. Stressed trees are more susceptible to insects, and mountain pine beetle populations and distribution at higher elevations are promoted by higher temperatures. In addition, wildfire frequency and extent are expected to increase, in some cases spreading from lower-elevation forests, decreasing the abundance of MOG trees across the landscape. Although the extent of this cover type may fluctuate over time, it is not likely to change substantially in a warmer climate unless frequent reburns occur.

Whitebark Pine Mixed Upper Subalpine Forest

Influenced by cold continental air masses, whitebark pine mixed upper subalpine forests are located at the highest elevations where trees exist in the Northern Rockies. Here, whitebark pine is found with subalpine fir, Engelmann spruce, mountain hemlock, and subalpine larch across 5 million acres, primarily on higher ridges and mountaintops. Historically, over 14 percent of the Northern Rockies could have consisted of whitebark pine forests, with late seral mixed fir-spruce patches mixed throughout.

Disturbance agents, including disease, insects, and climate comprise a stress complex that has greatly reduced whitebark pine populations (MOG and other ages) in western North America, leading to this species being classified as “threatened” in the United States. Extensive epidemics

of white pine blister rust and outbreaks of mountain pine beetles over the past several decades have reduced whitebark pine and favored spruce, fir, and nonforest vegetation in some places.

Whitebark pine and associated species developed under a stand-replacing fire regime on steep north slopes, and under a mixed-severity fire regime in other locations. More frequent high-intensity fires could further reduce MOG whitebark pine populations. Although mountain pine beetle outbreaks have occurred three times over the past century, the outbreak that started in the mid-2000s (and has continued) has been especially damaging. This outbreak has occurred during a period of climatic warming, which is known to facilitate high beetle populations.

The combined stress from disease, insects, and a warmer climate will lead to additional mortality in MOG whitebark pine. Blister rust will be an ongoing chronic stressor, causing extensive mortality, while beetle outbreaks and wildfire (both affected by a warmer climate) will occur periodically with potentially severe effects across large landscapes. The current transition of dominance from whitebark pine to subalpine fir, and to a lesser extent Engelmann spruce and lodgepole pine, is expected to continue. The loss of older, cone-bearing whitebark pine trees will make it difficult for this species to recover. Fire can, in some cases, create conditions in which whitebark pine can establish, but recovery is unlikely in the absence of extensive planting of rust-resistant pine seedlings. Land management may be a bigger factor than climate in dictating the future composition and extent of this forest type.

Pacific Northwest Region

Increasing air temperature, through its influence on soil moisture, is expected to cause changes in the abundance and distribution of tree species throughout the Pacific Northwest Region. Increased frequency and extent of wildfire and insect outbreaks will facilitate vegetation change by causing increased mortality of susceptible species. Drought- and fire-intolerant species will likely be reduced in abundance, affecting the structure and function of MOG forests. High-elevation MOG forests will experience declines in snowpack and longer growing-season droughts, increasing their vulnerability and the potential for more frequent disturbance. Increased abundance and distribution of nonnative species, as well as the legacy of past land uses, create additional stress for regeneration of native forest species.

At low elevations, MOG forests are relatively uncommon because of a long history of logging, although some MOG forests can be found in wilderness areas and other protected lands. At high elevations, MOG forests are more common because they are less accessible and were less affected by logging. The effects of climate change are summarized for 10 forest types:

- Douglas-fir/western hemlock forest
- Sitka spruce forest
- Douglas-fir/tanoak forest
- Pacific silver fir forest
- Mountain Hemlock forest

- Ponderosa pine forest
- Mixed conifer forest
- Subalpine forest
- Western juniper woodland
- Riparian woodland

Douglas-fir/Western Hemlock Forest

Douglas-fir/western hemlock forests are found from low to middle elevations in moist forest west of the Cascade Range. Douglas-fir is the primary canopy dominant, and western hemlock and western redcedar become increasingly important in MOG forests. Fires occurred multiple times a century prior to European colonization and played an important role in the development of MOG forest, particularly at lower elevation and drier locations in Oregon. Infrequent, high-severity fires also occurred at centennial scales, sometimes affecting large areas under extreme east-wind conditions.

Douglas-fir/western hemlock forests are expected to continue experiencing increased wildfire activity. The greatest increase in fire activity in moist forests is expected in the Oregon Cascades, particularly toward the south where lightning frequency is high and recent fire activity has increased the most. The Coast Range and Olympic Peninsula are expected to experience the biggest increases in fire relative to recent decades, but fire activity will remain low with the exception of drier locations in rain shadows (e.g., eastside Olympic Mountains, interior Coast Range along valley margins). Large, high-severity wildfires in moist forest are facilitated by synoptic east-wind events that are not projected to increase in frequency. However, more ignitions and fires burning during the late summer and early fall could produce more frequent high-severity fires even if winds do not change.

Insect outbreaks and pathogens are likely to increase in MOG forests as a result of increasing soil moisture deficits that stress trees, particularly in drought-intolerant species such as western hemlock and western redcedar. Root rots affect most coniferous species in moist forests and will likely decrease growth vigor and increase susceptibility to windthrow. Douglas-fir beetle preferentially affects larger-diameter (>40 cm) Douglas-fir in small patches but may affect larger areas following mortality from wind or fire. Winter windstorms are also an important component of the disturbance regime in these forests and may cause substantial mortality during regional-scale events.

Sitka Spruce Forest

Sitka spruce is the dominant forest in wet coastal areas, although MOG is relatively rare except in protected areas. The distribution of this zone is mostly limited to the coast and closely related to the occurrence of summer fog, extending inland along major river valleys. Other common tree species include Douglas-fir, western redcedar, and western hemlock. Fire was infrequent historically, although high-severity fires likely occurred under extreme drought or east-wind conditions. Winter windstorms are an important component of the disturbance regime in Sitka spruce forests and may cause substantial mortality during regional-scale events. More fog-free

days during the summer may have negative effects on growth by increasing vapor pressure deficits and contributing to drier fuel conditions that could facilitate fires.

Pacific Silver Fir Forests

Pacific silver fir forests occur at middle elevations where more of the annual precipitations falls as snow. MOG forests are dominated by noble fir and Pacific silver fir which increases in importance in mature and late seral stands. Douglas-fir and western hemlock may also be found in MOG forests, especially toward the lower extent of Pacific silver fir. Alaska yellow cedar may also be present on cool, north-facing aspects. Subalpine fir, lodgepole pine, and mountain hemlock may be present at higher elevations. Most species are relatively intolerant of fire. Contemporary fires in Pacific silver fir forests have high proportions of high-severity fire.

Pacific silver fir forests currently exist at the lower extent of the snow line and will be negatively affected by reduced snowpack. Loss of snowpack will increase vulnerability to higher disturbance frequency, particularly wildfire. Root rot pathogens are also a primary disturbance agent in MOG Pacific silver fir forests. Higher temperatures and more frequent drought could reduce tree growth and increase susceptibility to mortality.

Mountain Hemlock Forest

MOG mountain hemlock forests are commonly dominated by monospecific stands of mountain hemlock. Lodgepole pine and western white pine may also be present, as well as other high-elevation conifers including subalpine fir and whitebark pine in drier locations. Mountain hemlock forests are composed primarily of fire-intolerant species. Historically, wildfire in this forest type was infrequent, and contemporary fires have high proportions of high-severity burns.

Mountain hemlock forests will experience reduced snowpack and longer growing seasons, and will be especially vulnerable to increased disturbance frequency, particularly wildfire. Warmer temperatures and more frequent drought could increase susceptibility to mortality from biotic disturbances and reduced growth. Laminated root rot is a primary disturbance agent in MOG mountain hemlock forests. Root rot patches spread slowly over time and kill mature trees.

Subalpine Forest

Subalpine forests and woodlands occur in relatively dry locations at the highest elevations, dominated by subalpine fir, Engelmann spruce, western white pine, lodgepole pine, and whitebark pine. Subalpine larch occurs in the northern Cascades of Washington. Mountain hemlock and Alaska yellow cedar may be present in the moister portion of the distribution of subalpine forests.

Wildfires have already affected large extents of MOG subalpine forests. In addition to fire, subalpine MOG forests are especially vulnerable to increased frequency of low-snow years. Warmer temperatures and more frequent drought could increase susceptibility to mortality from insects and pathogens, as well as reduced growth. Lodgepole pine is susceptible to epidemic outbreaks of mountain pine beetle, and both whitebark pine and western white pine have suffered extensive mortality from the invasive white pine blister rust.

Ponderosa Pine Forest

MOG ponderosa pine forests and woodlands are comprised mostly of ponderosa pine and multiple species of shrubs and perennial grasses. Frequent low-severity wildfire was common prior to European colonization but has been infrequent during the last century. Fire exclusion, grazing, and high-grade logging of the largest trees altered the structure of MOG forests, many of which currently have high densities of small trees and a reduced large-tree component.

MOG forests are currently vulnerable to large patches of high-severity fire and outbreaks of insects including mountain pine beetle and pine butterfly. High stem density also makes MOG forests susceptible to drought-related mortality as temperatures increase and acute summer droughts become more frequent and intense. Invasions of nonnative annual grasses may increase fire frequency and affect native plant communities in MOG forest and woodlands.

Mixed Conifer Forest

MOG mixed conifer forests occur across a broad range of moisture conditions at middle elevations in dry forest landscapes of the region. Ponderosa pine is the most common and dominant early-seral species, although western larch is common in the Blue Mountains and northeastern Washington. Frequent wildfire in both dry and moist mixed conifer forests maintains large trees of these drought and fire resistant species. However, fire exclusion and high-grade logging of the largest trees have altered the structure and composition of mixed conifer forests, greatly reducing MOG. Current basal area and density are much higher than they were historically because shade-tolerant cohorts of white fir, grand fir, and Douglas-fir have increased. Grand fir transitions to white fir as a dominant species in the southern Cascades. Incense cedar, lodgepole pine, and western white pine may occur throughout, and sugar pine from central Oregon southwards.

Large patches of high-severity fire will be a primary stressor in MOG forests, and increased frequency and extent of wildfire will favor the fire-tolerant species ponderosa pine and Douglas-fir. Increased frequency and extent of droughts will potentially affect all species, making them more susceptible to secondary factors such as insects. Sugar pine and western white pine are affected by the invasive white pine blister rust. Mortality may be prominent in MOG forests with high stem densities, with firs being especially susceptible. Drought-tolerant species such as ponderosa pine (although this species is susceptible to bark beetles) and Douglas-fir may be "winners" in the long term, comprising a greater proportion of future MOG forests. Mortality and altered species distribution and abundance will be greater where soil moisture is relatively low—south aspects, steep slopes, and lower elevations.

Douglas-Fir/Tanoak Forest

Douglas-fir/tanoak forests are common at low to middle elevations in the Klamath Mountains of southwestern Oregon. Douglas-fir is dominant, but tanoak and other hardwood species including Pacific madrone, bigleaf maple, chinkapin, and canyon live oak are common. Frequent, low- and mixed severity fire was an integral art of the development of MOG Dougal-fir/tanoak forests

prior to European colonization. Topography played an important role in the distribution and abundance of species as well as patterns of fire severity.

Fire exclusion and drought have increased the susceptibility of Douglas-fir/tanoak forests to high-severity fire. Large trees are vulnerable to mortality and decreased growth from competitive effects associated with increased forest density. Hardwood species can resprout following high-severity fire but may be top-killed resulting in loss of large tree dominance. Invasions of non-native annual grasses are of concern and may increase fire frequency and affect native plant communities in MOG forest and woodlands.

Douglas-fir is vulnerable to mortality from drought and beetles, particularly in warmer, drier topographic settings at low elevations. Tanoak has suffered extensive mortality from sudden oak death, resulting elevated levels of large woody fuels that can increase the intensity of fire following infection and mortality.

Western Juniper Woodland

Western juniper woodlands are found at the lowest elevations in the warmest and driest portions of eastern Oregon (with a small amount in eastern Washington), dominated by western juniper and several species of shrubs and perennial grasses. Western juniper is one the most drought-tolerant and longest-lived species in the region, often reaching >1,000 years. Fires were generally infrequent historically but generally severe due to the thin bark and low fire tolerance of western juniper. Fire frequency was historically limited by a lack of fuels to carry fire, but western juniper experienced a long period of recruitment and expansion during the 20th century and is vulnerable to invasion of nonnative annual grasses (e.g., cheatgrass, medusahead).

Western juniper is vulnerable to high-severity fires, especially in areas where invasive grasses now provide a continuous fuel bed to carry fire. Mature trees are susceptible to mistletoe which can reduce growth and cause branch dieback. Local topographic and site factors (e.g., soils) play an important role in the structure of MOG, and more woodlands that are isolated from other continuous forests may provide refugia from future drought and wildfire.

Riparian Woodland

Riparian woodlands can contain several hardwood species—alders, cottonwoods, willows, maples, quaking aspen and sometimes conifers. Species composition varies across the region depending on local hydrology, with major differences between the eastside and westside Cascades. These species often achieve MOG structure in the absence of wildfire and other disturbances. Higher temperature and evapotranspiration will contribute to drying and increased drought sensitivity in some riparian areas. Riparian vegetation depends on the presence of flowing water. With climate change, summer streamflow will decrease because of earlier snowmelt and earlier runoff. Some riparian areas may serve as refugia for species dependent on cooler conditions, and dense vegetation may buffer increased temperature, especially in topographically complex landscapes where cold-air drainage affects the microclimate.

The primary effects of climate change on riparian woodlands will likely be mediated through disturbance. Increased drought frequency may decrease the extent of the riparian zone in some locations and/or alter riparian vegetation composition. More frequent wildfires may kill (or at least top-kill) MOG hardwoods as well as favor nearby fire-tolerant conifers, although most hardwood species sprout vigorously. Increased flooding may uproot MOG in some riparian areas as a result of lower snowpack and increased intensity of winter precipitation events. Increased peak flows can create erosion and sedimentation, which in turn affect channel form and the fluvial dynamics of streams and their riparian zones.

Pacific Southwest Region

Increasing air temperature, through its influence on soil moisture, is expected to cause gradual changes in the abundance and distribution of tree species throughout the Pacific Southwest Region. Fire and drought-tolerant species will likely become more competitive. Ecological disturbance, including wildfire and insect outbreaks, will be a primary facilitator of vegetation change, and future forest landscapes may be dominated by younger age classes and smaller trees. Low elevations are expected to experience increasingly long and severe droughts, coupled with an increase in fire activity where fuels are not limiting. Higher-elevation forests will experience declines in snowpack and longer growing seasons and are especially vulnerable to increased disturbance frequency including insects and wildfire. Increased abundance and distribution of nonnative species, as well as the legacy of past land uses, create additional stress for regeneration of native forest species that interact with climate change.

At lower elevations, MOG forests are relatively uncommon because of a long history of logging and other land uses, although some MOG forests can still be found in wilderness areas and other protected lands. At high elevations, MOG forests are more common because they are less accessible, were less affected by logging, and are the focus of recent conservation efforts. The effects of climate change are summarized for six forest types:

- Redwood forest
- Douglas-fir/tanoak forest
- Foothill forest and woodland
- Subalpine/red fir/Shasta red fir forest
- Ponderosa pine forest
- Mixed conifer forest

Redwood Forest

Redwood is the dominant forest type in wet coastal areas from central California north, although MOG are relatively rare except for in protected areas. The distribution of this zone is mostly limited to the coast and closely related to the occurrence of summer fog, extending deeper inland along river valleys and transitioning to grasslands and woodlands in drier uplands. In addition to coast redwood, common tree species include Sitka spruce, grand fir, western redcedar, and

western hemlock in coastal areas, and Douglas-fir and tanoak farther inland where there is less fog. Low- and moderate-severity wildfire was relatively frequent historically as a result of burning by American Indians, particularly in warmer inland areas and to the south. Winter storms are an important component of the disturbance regime and are often associated with high winds, landslides, and flooding.

More fog-free days during the summer could have negative effects on growth by increasing vapor pressure deficits. The effects of increasing summer moisture deficits may be greatest on western redcedar and western hemlock that occur in the southern part of their range. Warmer, drier conditions in the summer will also contribute to drier fuel conditions that could facilitate high-severity fires. These fires would potentially cause high mortality in all conifer species in MOG forests, although redwood can sprout vigorously.

Douglas-Fir/Tanoak Forest

Douglas-fir/tanoak forests are common at low to middle elevations in the Klamath Mountains of northern California. Douglas-fir is dominant, but tanoak and other hardwood species including Pacific madrone, bigleaf maple, chinkapin, and multiple species of oak (e.g., canyon live oak, California black oak, Oregon white oak) may be present. Frequent, low- and mixed-severity fire was an integral art of the development of MOG Douglas-fir/tanoak forests prior to European colonization. Topography played an important role in the distribution and abundance of species as well as patterns of fire severity.

Fire exclusion and drought have increased the susceptibility of Douglas-fir/tanoak forests to high-severity fire. MOG trees are vulnerable to mortality and decreased growth from competitive effects associated with increased forest density. Hardwood species can resprout following high-severity fire but may be top-killed, resulting in loss of large-tree dominance. Invasions of nonnative annual grasses may increase fire frequency and affect native plant communities in MOG forests.

Douglas-fir is vulnerable to mortality from drought and beetles, particularly in warmer, drier topographic settings at low elevations. Tanoak has suffered extensive mortality from sudden oak death, resulting elevated levels of large woody fuels that can increase the intensity of fire following infection and mortality. The interaction of these multiple stressors with a warmer climate will increase the susceptibility of this forest type in the future.

Foothill Forest and Woodland

Foothill forests and woodlands occur at the lowest elevations around valley margins and the foothills of larger mountain ranges. Foothill forests often intermingle with meadows and chaparral at the low end of their elevational distribution and transition to conifer-dominated forest types at the upper end. Several oak species are found in this forest type, including coast live oak, interior live oak, blue oak, canyon live oak, black oak, and Oregon white oak. Gray pine, knobcone pine, and Coulter pine are the most common conifers. All dominant tree species are generally drought tolerant.

Frequent, low-severity fire historically played a major role in the development of MOG foothill forests and woodlands. Some MOG foothill forest and woodlands are still abundant, particularly those dominated by blue oak, but fire exclusion and grazing have altered their structure and composition by promoting increased densities of small trees and conifer encroachment in places.

MOG foothill forest and woodlands are at risk of high-severity fire and drought-related mortality from increased density and competition with smaller trees. Although oaks will resprout following fire, high-severity fire may top-kill large trees that are an important component of MOG structure. Invasions of nonnative annual grasses may increase fire frequency and affect native plant communities in MOG forests and woodlands. Most dominant species are relatively resistant to native insects and pathogens, but sudden oak death has the potential to infect and kill large coast live oak, black oak, and canyon live oak trees.

Subalpine/Red Fir/Shasta Red Fir Forest

Subalpine, red fir, and Shasta red fir forests occur at high elevations in mountainous landscapes. Red fir and Shasta red fir forests are generally located in more productive environments than subalpine forests but share many of the same climatic conditions. Western white pine, whitebark pine, lodgepole pine, and mountain hemlock are also common; Brewer spruce, limber pine, and foxtail pine are less common. Wildfire was moderately frequent but highly variable and predominantly low and moderate severity historically. Current MOG forests have higher canopy cover and density of small trees than prior to fire exclusion, especially in red fir and Shasta Red fir forests.

Loss of snowpack will increase drought stress during the growing season while higher temperatures will increase water demand, especially later in the growing season. Higher temperatures and longer growing seasons will likely increase the frequency and extent of fire, insect outbreaks, and pathogens. MOG red fir and Shasta red fir have recently experienced significant tree morality from the combined effects of drought, insects, and pathogens. Lodgepole pine is susceptible to mountain pine beetles, and western white pine and whitebark pine are susceptible to the invasive white pine blister rust, especially in moister landscape positions.

Ponderosa Pine Woodland and Forest

MOG ponderosa pine woodlands and forests are comprised mostly of ponderosa pine and multiple species of shrubs and perennial grasses. Frequent low-severity fire was common prior to European colonization but was largely absent during the past century. Fire exclusion, grazing, and high-grade logging of the largest trees have altered the structure of MOG forests which currently have an increased density of small trees and a reduced large-tree component.

MOG forests are currently vulnerable to large patches of high-severity fire and outbreaks of insects including mountain pine beetle and pine butterfly. Increased density also makes MOG forests susceptible to drought-related mortality as temperatures increase and acute summer droughts become more frequent and intense. A recent (2010–2016) large-scale mortality event in the Sierra Nevada (>100 million trees killed) corroborates the synergistic effects of drought and

insects. Invasions of nonnative annual grasses may increase fire frequency and affect native plant communities in MOG forests and woodlands.

Mixed Conifer Forest

Mixed conifer MOG forests occur across a broad range of moisture conditions at middle elevations in dry forest landscapes in the Pacific Southwest region. Ponderosa pine is a common and dominant early-seral species. Jeffrey pine, sugar pine, and western white pine may also be present. Giant sequoia is found in scattered stands on the western slope of the Sierra Nevada. Frequent wildfire in both dry and moist mixed conifer forests maintained the dominance of large trees of the drought- and fire-resistant sequoias. Fire exclusion and high-grade logging of the largest trees of all species altered the structure and composition of mixed conifer MOG forests. Current basal area and density are much higher than there were historically because of ingrowth of shade-tolerant cohorts of white fir, incense cedar, and Douglas-fir.

Large patches of high-severity wildfire are a primary vulnerability in mixed conifer MOG forests, and increased frequency and extent of fire in the future will favor the fire-tolerant species ponderosa pine and Douglas-fir. Increased frequency and extent of droughts will potentially affect all species, making them more susceptible to secondary factors such as insects. Sugar pine and western white pine are affected by the invasive white pine blister rust. Mortality may be prominent in MOG forests with high stem densities, and firs may be especially susceptible. Drought-tolerant species such as ponderosa pine (although this species is susceptible to bark beetles) and Douglas-fir may be "winners" in the long term, comprising a greater proportion of future MOG forests. Mortality and altered species distribution and abundance will be greater where soil moisture is relatively low—south aspects, steep slopes, and lower elevations.

Rocky Mountain Region

Increasing air temperature, through its influence on soil moisture, is expected to cause gradual changes in the abundance and distribution of tree species throughout the Rocky Mountain Region, with more drought-tolerant species becoming more competitive. The earliest changes will be at ecotones between lifeforms (e.g., upper and lower treelines). Ecological disturbance, including wildfire and insect outbreaks, will be a primary facilitator of vegetation change, and future forest landscapes may be dominated by younger age classes and smaller trees. High-elevation forests will experience declines in snowpack and will be especially vulnerable to increased disturbance frequency. Increased abundance and distribution of nonnative species, as well as past land uses, create additional stress for regeneration of native forest species.

Forest vegetation in the Rocky Mountain Region is diverse, ranging from mixed conifer forests on high mountains in Colorado to semiarid ponderosa pine forests in South Dakota, to whitebark pine woodlands in Wyoming. At low elevations, MOG forests are relatively uncommon because of a long history of logging, although some MOG forests can still be found in wilderness areas and other protected lands. At high elevations MOG forests are more common because they are less accessible and were less affected by logging. However, mountain pike beetles have caused

extensive mortality in lodgepole pine forests over the past 30 years. The effects of climate change are summarized for seven forest types:

- Pinyon-juniper forest
- Ponderosa pine forest
- Mixed conifer forest
- Lodgepole pine forest
- Subalpine forest
- Quaking aspen forest
- Riparian woodland

Pinyon-Juniper Forest

Pinyon-juniper forests, comprised of two-needle pinyon pine and three different juniper species, are found primarily at lower elevations in southern and western Colorado. Drought can reduce the vigor of pinyon pine, increasing their susceptibility to bark beetle outbreaks that can cause extensive tree mortality. Recent drought-provoked outbreaks in Arizona and Nevada killed as much as 90 percent of the dominant overstory pinyon pines. Juniper species are typically more drought tolerant than pinyon pine but can also be stressed by long droughts. Both species are especially susceptible to drought-induced mortality on the hottest and driest landscape positions.

Pinyon pine and juniper are fire intolerant. Therefore, an increase in the frequency and extent of wildfire will be a major stressor in the future, although the fire effects will vary depending on stand structure and fuel loading. Forests with high stem densities and high fuel loadings are conducive to crown fires and mortality of most of the MOG trees, whereas forests with low stem densities and low fuels may not generate flames high enough to propagate crown fires.

Ponderosa Pine Forest

Ponderosa pine forests are distributed mostly at lower elevations, often at lower treeline, extending into the lower distribution of mixed conifer forests. Ponderosa pine is often associated with subdominant Gambel oak, and is mixed with shrubs (e.g., sagebrush) and grasses at the lowest and driest extent of its distribution. Large areas of MOG are uncommon in this forest type, although stands or small groups of large trees are relatively common where logging has not occurred for several decades.

Ponderosa pine has a deep taproot, which allows it to tolerate drought. However, several consecutive years of drought can weaken trees enough to make them susceptible to lethal bark beetle outbreaks. If droughts occur more frequently, early effects on ponderosa pine can be expected in the driest landscape positions (e.g., south aspects, steep slopes). Historically, ponderosa pine forest had a high-frequency/low-intensity fire regime; even relatively small trees often survived fire. However, increased wildfire in the future may be a stressor in areas where high fuel loadings can propagate crown fires.

Mixed Conifer Forest

Mixed conifer forests are comprised of a broad range of conifer and some hardwood species at mid elevations in the Southwest. Dominant species include Douglas-fir, ponderosa pine, white fir, Rocky Mountain juniper, and blue spruce; subalpine fir and Engelmann spruce are found in colder areas. Mixed conifer encompasses a significant amount of MOG forest where logging and recent disturbances have not been a factor. Patches of quaking aspen are commonly found in mixed conifer forests, and although it is often considered an early-seral species, it can achieve MOG conditions in the absence of disturbance and competition from conifers.

Increased frequency and extent of droughts will potentially affect all species, making them more susceptible to secondary factors such as insects. Mortality may be prominent in MOG forests with high stem densities; spruces and firs may be especially susceptible. Drought tolerant species such as ponderosa pine (although this species is susceptible to bark beetles) and Douglas-fir may be "winners" in the long term, comprising a greater proportion of future MOG forests. Mortality and altered species distribution and abundance will be greater where low soil moisture is prevalent—south aspects, steep slopes, and lower elevations. Historically, this forest type experienced mostly low-severity and mixed-severity wildfire. Increased frequency and extent of fire in the future will tend to favor the fire-tolerant species ponderosa pine and Douglas-fir.

Lodgepole Pine Forest

Lodgepole pine tolerates a wide variety of climatic and soil conditions, achieving its best growth on gentle slopes and in basins with well-drained soils. This species is often found in nearly pure stands but intergrades with mixed conifer and subalpine forests in many locations. Because lodgepole pine often germinates prolifically following wildfire, stands tend to be of uniform age and can achieve MOG conditions over time in the absence of insects and fire.

Old, low-vigor, high-density lodgepole pine stands are susceptible to mountain pine beetles. Beetle populations are stimulated by higher temperatures, spreading from stressed trees to adjacent healthy trees in large outbreaks, and will be a major stressor in a warmer climate. Stimulated by recent warming, beetles have killed lodgepole pine forests across large landscapes in the past 30 years, including MOG stands. Lodgepole pines are relatively fire intolerant and have serotinous cones that disperse seeds quickly after a wildfire passes. Therefore, it is expected that this species will persist in a warmer climate, but more frequent wildfire combined with increased beetle outbreaks will make it difficult to achieve MOG conditions.

Subalpine Forest

Subalpine forests occupy a large portion of the highest elevations where tree species exist in the region. Engelmann spruce and subalpine fir are the dominant species; blue spruce and lodgepole pine are present in cooler, wetter sites, and limber pine and Rocky Mountain bristlecone pine are present on more exposed sites. MOG stands that have not been subject to logging are common, especially in wilderness areas.

Where adequate soil moisture is available, higher temperature and a longer growing season may increase (or at least maintain) growth and productivity for subalpine species, especially at the

highest elevations. However, at lower elevations within the subalpine zone and other locations where snowpack decreases significantly, low soil moisture may decrease growth and subject MOG trees to stress during the growing season. This could in turn make these forests more susceptible to insects, especially spruce beetle and spruce budworm, especially in dense, older forests.

None of the common species in subalpine forests are fire tolerant. As fire frequency and extent increase in the future, it is likely that wildfire will increasingly spread from mixed conifer forests into subalpine forests, killing large areas of MOG subalpine forest. The potential for post-fire regeneration will be variable, and lower-elevation tree species may displace spruce and fir in the lower portion of the subalpine zone. Whitebark pine (found only in Wyoming) will be particularly susceptible to a stress complex of white pine blister rust and climate-related increases in mountain pine beetle outbreaks and wildfire.

Quaking Aspen Forest

Quaking aspen is widely distributed in the region, often embedded with conifer forests, ranging from dry, high-elevation sites to poorly drained meadows. Although it is often considered an early-seral species, it can achieve MOG conditions in the absence of disturbance and competition from conifers. Aspen is susceptible to several insect and pathogen species.

There has been considerable discussion about "aspen decline" over the past 20 years. It appears that mortality has been highest in the driest landscape positions—exposed sites and south-facing slopes. A warmer, drier climate may facilitate additional mortality, first in the driest locations, then perhaps elsewhere. Aspen can be top-killed by wildfire but sprouts vigorously. With increased wildfire frequency, aspen may exist primarily in younger stands that never achieve MOG structure.

Riparian Woodland

Riparian woodlands contain several hardwood species mixed with other herbaceous plants near streams and other water bodies. Riparian areas are often embedded within conifer and aspen forests. Species composition varies depending on local hydrology and topography. MOG trees in riparian areas provide habitat for many birds, mammals, and other fauna. Most of the hardwood trees tend to be short-lived but regenerate quickly by seed or sprouting following disturbances. Many riparian woodlands have a significant component of nonnative invasive species that are tolerant of saline conditions and low soil water, especially saltcedars and Russian olive, that can greatly reduce water availability for native species. These invasives, which are an ongoing stressor, will likely increase in a warmer climate.

If temperature and drought frequency increase as projected, the hydrology of riparian woodlands will be altered relatively quickly. This will decrease the abundance and diversity of native hardwood species that require a reliable water supply during the growing season, in some cases killing stressed MOG trees. In addition, drier conditions in riparian areas may reduce fuel moisture in riparian woodlands, making them more susceptible to wildfire that spreads from

adjacent vegetation. These fires will likely kill many of the MOG trees, although some species can sprout quickly.

Pacific Southwest Region

Higher temperature, independent of other climate-related factors, is expected to create considerable stress for many forest landscapes in the Pacific Southwest Region, especially on south and west aspects. Many forests in this region are already subjected to periods of low water availability, and increasing temperature will exacerbate the demand for water. Multi-year droughts, which have been common in the Southwest over the past 20 years, provide an additional stress that will likely become more common in the future. This will affect most mid- to low-elevation forests, ranging from MOG trees to regeneration. This is expected to cause a gradual change in the distribution and abundance of dominant forest species, and in some cases will facilitate a transition from forests to nonforest vegetation.

Insect outbreaks are also expected to be significant stressors, often being the ultimate cause of mortality in drought-stressed forests. An increase in the frequency and extent of wildfire will be an additional stressor, especially where fuel loadings are high, often killing MOG trees and inhibiting regeneration. Nonnative plant species, especially annual grasses (e.g., cheatgrass) will likely continue to expand, potentially displacing native species and altering fire regimes. A combination of stressors (stress complexes), exacerbated by climate, may accelerate the rate of change in forest ecosystems, reducing productivity and carbon storage. Declining snowpack will decrease soil moisture, contributing to altered distribution of montane forest species.

At low to mid elevations, MOG forests comprised of large conifer species (e.g., ponderosa pine) are uncommon because of a long history of logging, although some MOG forests can still be found in protected lands. MOG stands can often be found at low to mid elevations where forests contain woodlands (e.g., oaks) and conifer forests (e.g., pinyon pine) with low commercial value. At high elevations, MOG forests are more common because they are less accessible and were less affected by logging. The effects of climate change are summarized for six forest types:

- Pinyon-juniper forest
- Ponderosa pine forest
- Mixed conifer forest
- Subalpine forest
- Oak woodland
- Riparian forest

Pinyon-Juniper Forest

Pinyon-juniper forests are extensive at lower elevations in the Southwest. Multiple pinyon pine and juniper species are often mixed with grasses, sagebrush, and evergreen shrubs at the lowest extent of their distribution, and with oaks and ponderosa pine at higher elevations. Drought can reduce the vigor of pinyon pine, increasing their susceptibility to bark beetle outbreaks that can

cause extensive tree mortality. Recent drought-provoked outbreaks in Arizona and Nevada have killed as much as 90 percent of the dominant overstory pinyon pines in some places. Juniper species are typically more drought tolerant than pinyon pine but can also be stressed by long droughts, and both species are susceptible to drought-induced mortality on hot, dry sites.

Pinyon pine and juniper species are fire intolerant. Therefore, an increase in the frequency and extent of wildfire could become a major stressor in the future, although fire effects will vary depending on stand structure and loading. Forests with high stem densities and high fuel loadings are conducive to crown fires and mortality of most of the MOG trees, whereas forests with low stem densities and low fuels may not generate flames high enough to propagate crown fires, allowing MOG trees to survive.

Ponderosa Pine Forest

Ponderosa pine forests lie between pinyon-juniper and mixed conifer forests, both of which contain a significant component of ponderosa pine. At the lowest extent of its distribution, ponderosa pine is often associated with subdominant Gambel oak and evergreen oak species, as well as shrubs (e.g., sagebrush) and grasses. MOG trees are not widespread in this forest type, although stands or small groups of large trees are relatively common where logging has not occurred for several decades.

Ponderosa pine has a deep taproot that allows it to tolerate drought. However, several consecutive years of drought can weaken trees enough to make them susceptible to lethal outbreaks of bark beetles, which has occurred recently in the Sierra Nevada of California. If droughts occur more frequently in the Southwest, early effects on ponderosa pine can be expected in the driest landscape positions (e.g., south aspects, steep slopes). Historically, ponderosa pine forest had a high-frequency/low-intensity fire regime; even relatively small trees often survived fire. However, increased wildfire in the future may be a stressor in areas where high fuel loadings can propagate crown fires.

Mixed Conifer Forest

Mixed conifer forests are comprised of a broad range of conifer and some hardwood species at mid elevations in the Southwest. Dominant species include Douglas-fir, ponderosa pine, white fir, blue spruce, corkbark fir, and southwestern white pine; subalpine fir and Engelmann spruce are found in colder areas. Mixed conifer forests encompass a significant amount of MOG forest where logging and recent disturbance (e.g., fire and insects) have not been a factor. Patches of quaking aspen are commonly found in mixed conifer forests, and although it is often considered an early-seral species, it can achieve MOG structure in the absence of disturbance and competition from conifers.

Increased frequency and extent of droughts will potentially affect all species, making them more susceptible to secondary factors such as insects. Mortality may be prominent in MOG forests with high stem densities; spruces and firs may be especially susceptible. Drought-tolerant species such as ponderosa pine (although this species is susceptible to bark beetles) and Douglas-fir may be “winners” in the long term, comprising a greater proportion of future MOG forests. Mortality

and altered species distribution and abundance will be greater where lower soil moisture is more likely—south and west aspects, steep slopes, and lower elevations. Increased frequency and extent of wildfire in the future will also favor fire-tolerant ponderosa pine and Douglas-fir.

There has been considerable discussion about "aspen decline" over the past 20 years. It appears that mortality has been highest in the driest landscape positions—exposed sites and south-facing slopes. A warmer, drier climate may facilitate additional mortality, first in the driest locations, then perhaps elsewhere. Aspen can be top-killed by wildfire but sprouts vigorously. With increased fire frequency, aspen may exist primarily in younger stands that never achieve MOG structure.

Subalpine Forest

Subalpine forests occupy the highest elevations where tree species exist in the region. Engelmann spruce and subalpine fir are the dominant species, with blue spruce and lodgepole pine present in cooler, wetter sites; species such as limber pine and southwestern white pine are present on more exposed sites. MOG stands that have not been subject to logging are relatively common, especially in wilderness areas.

Where adequate soil moisture is available, higher temperature and a longer growing season may increase (or at least maintain) growth and productivity for these species, especially at the highest elevations. However, at lower elevations within the subalpine zone and other locations where snowpack decreases significantly, low soil moisture may decrease growth and subject MOG trees to stress during the growing season. None of the common species in subalpine forests are fire tolerant. As fire frequency and extent increase in the future, it is likely that wildfire will increasingly spread from mixed conifer and ponderosa pine forests into subalpine forests, killing large areas of MOG subalpine forest. The potential for post-fire regeneration will be variable (but reliable for lodgepole pine), and lower-elevation tree species may displace subalpine species over time.

Oak Woodland

Gambel oak, a deciduous species, and several evergreen oak species are broadly distributed at lower elevations, often on drier aspects mixed with pinyon-juniper and ponderosa pine forests. Oak woodlands have experienced low regeneration throughout the region during the extensive drought of the past 20 years or so. Because the frequency and duration of drought are expected to increase in the future, poor regeneration is expected to continue, and MOG oaks may experience mortality in locations where low soil moisture is persistent. Oaks will persist where microclimate (e.g., north aspects), poorly drained soils, and adjacency to riparian areas provide sufficient moisture for long-term tree growth.

Climate change is expected to increase the frequency and extent of wildfire throughout the Southwest. Oak woodlands often have high loadings of very dry fuels, so when fires occur, they will be of high intensity, top-killing most or all trees including MOG oaks. Many oak species sprout vigorously after fire, but the MOG structure will be lost for several decades. In some locations, fire frequency may be so high that MOG structure will rarely develop.

Riparian Woodland

Riparian woodlands contain several hardwood species (e.g., Fremont cottonwood, Arizona sycamore, boxelder, willows, and sometimes conifers). Most of the hardwood trees tend to be short-lived but regenerate quickly by seed or sprouting following disturbances. Many riparian woodlands have a significant component of nonnative invasive species, which are an ongoing stressor, and will likely spread in a warmer climate.

If temperature and drought frequency increase as projected, the hydrology of riparian woodlands will be altered relatively quickly. This will decrease the abundance and diversity of native hardwood species that require a reliable water supply during the growing season, in some cases killing MOG trees that are highly stressed. In addition, drier conditions may reduce fuel moisture in riparian woodlands, making them more susceptible to wildfire that spreads from adjacent vegetation. These fires will likely kill many of the MOG trees, although some species can sprout vigorously.

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