Idaho Climate-Economy Impacts Assessment
Forests Report

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Key messages

1. Forests cover a substantial portion of Idaho, and provide multiple ecosystem services, including timber, recreational opportunities, carbon sequestration, and habitat.
2. Climate affects Idaho's forests through temperature and precipitation. Idaho's forests have warmed in the last few decades, and projected future climate change suggests continued warming, as well as greater annual precipitation and reduced summer precipitation.
3. Direct responses of Idaho tree species to climate change will vary depending on species and location. For one tree species, lower-elevation trees will experience less favorable conditions from hotter, drier conditions, and higher-elevation trees will experience more favorable conditions associated with warming and longer growing seasons. Because of limitations in understanding about future precipitation and tree response, the changes in Idaho trees in terms of range shifts, abundance, and productivity are uncertain.
4. Recent climate conditions have led to widespread and severe forest disturbances in Idaho, including substantial tree mortality. Wildfires and bark beetles benefit from warmer, drier conditions. Future climate change will lead to more frequent and severe disturbances, affecting tree growth and survival. The combination of climate change and enhanced disturbances may lead to the enhanced susceptibility of forests to disturbances and reduced ability to recover.
5. Climate change will impact ecosystem services provided by forests, including timber, recreational opportunities, and habitat for other species.
6. Opportunities exist for Idaho forests to sequester carbon, thereby reducing (mitigating) future climate change. Idaho forests may participate as carbon offset projects in existing carbon markets while allowing for traditional forest uses. Management actions also can utilize trees to help humans and other species adapt to future climate change.

1. Forests of Idaho

The forests of Idaho have long played a fundamental role for inhabitants. They have provided shelter; sustenance; jobs in silviculture, logging, and manufacturing; the land base upon which homes and structures have been built; and areas for hunting and recreation. Decades of wildfire suppression coupled with federal forest policy changes in the 1990s have created forest conditions susceptible to increased risk of wildfire, insects, and disease, exacerbated by an increasingly warm and dry climate. The increased risks, and various ownerships' responses to increased risk, have important impacts on the state's forest resources and economy. To understand the potential economic risks to Idaho forests from climate change, it is necessary to understand the underlying resource base and ownership structure. This report first takes a brief look at the forest land base and resource characteristics, and how they have changed in the recent past. It then presents the contributions to Idaho's economy through timber harvesting and forest products manufacturing. After that, the report identifies how forests are affected by climate change, and provides an overview of studies that explore climate change impacts. The final section lays out mitigation and adaption options.

One of the primary sources of forest resource characteristics for the United States is the U.S. Department of Agriculture (USDA) Forest Service's Forest Inventory and Analysis (FIA) program. The FIA is a continuous forest inventory consisting of over 140,000 forested plots measured at regular intervals covering the entire conterminous U.S. and parts of Alaska (Roesch and Reams, 1999). In the eastern U.S., these plots are revisited as often as every five years, while in the west, including Idaho, they are visited once every ten years. Measurements from these plots form the basis for the national greenhouse gas (GHG) inventory that is used for both domestic and international policy communications (U.S. Environmental Protection Agency (EPA), 2021 and U.S. Department of State (DoS), 2021). Figure 1 shows the land use breakdown of the 53.7 million acres covered in this FIA sample. Forest and range are the most dominant land uses, each covering 40% (21.7 and 21.6 million acres, respectively) of the land base in Idaho, with agriculture the next dominant use at ~13% (6.9 million acres), followed by other uses like wetlands or non-vegetated areas covered by snow or ice at 4.4% (2.3 million acres). Developed uses form the smallest land use component, representing just over 2% (1.1 million acres) of the land base. In Idaho, the current inventory includes 3,753 forested plots representing on average 5,945 acres per plot. The most recent inventory includes measurements on those plots recorded between the 2010 and 2019 field seasons.

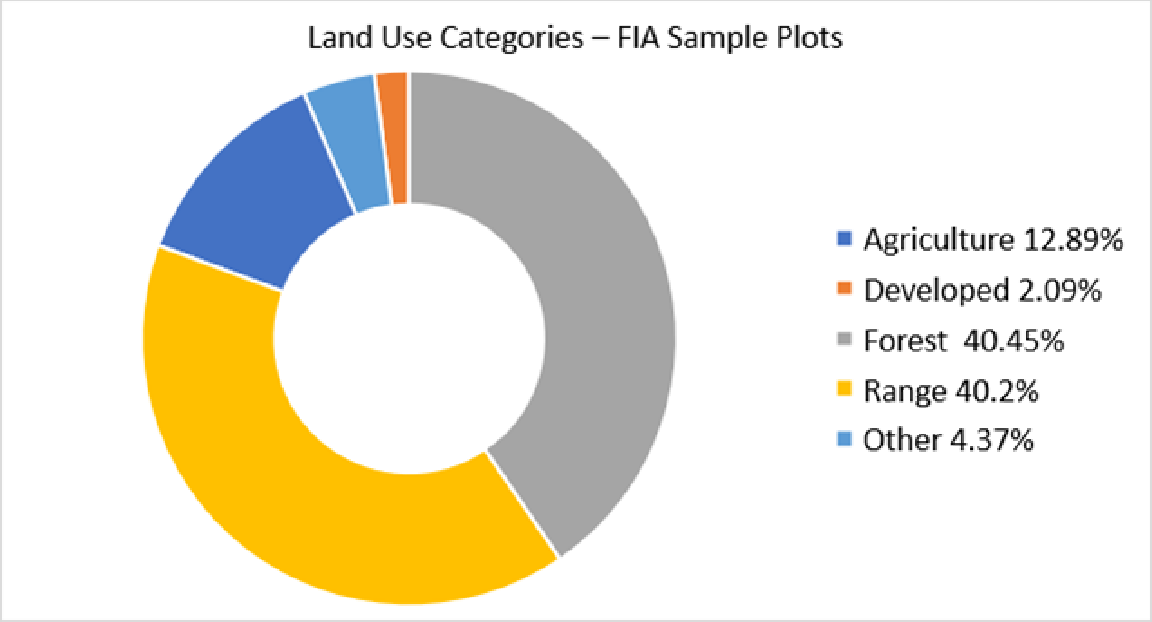


Figure 1. Land use in Idaho based on FIA sample plots from 2010 to 2019 (USDA Forest Service, 2021).

The degree to which climate affects Idaho forests will depend in part on forest ownership and the management actions that forest owners undertake. Figure 2 presents a map of the 3,753 forested plots differentiated by ownership. The U.S. Forest Service (USFS) is the dominant landowner; 16.5 million acres of forest holdings encompass 76.0% of the forest land base in Idaho. Private forest landowners are the next highest group, with 2.9 million acres comprising 13.5% of Idaho forests, followed by 1.3 million acres (5.9%) and 1.0 million acres (4.6%) for state and other federal owners, such as the Bureau of Land Management (BLM), respectively. Figure 3 shows the harvest and inventory levels by owner in 2019. As shown on the right side of the figure, while the USFS manages 76% of the forest land base containing 81% of the forest inventory, the USFS contributes only 13% of the state harvest. Meanwhile, private lands, which cover 13.5% of the land base and contain 10% of the standing stock, contribute 64% of the harvested volume. It should be noted that 3.7 million acres, 22% of the USFS land base, is in some sort of a reserved status.

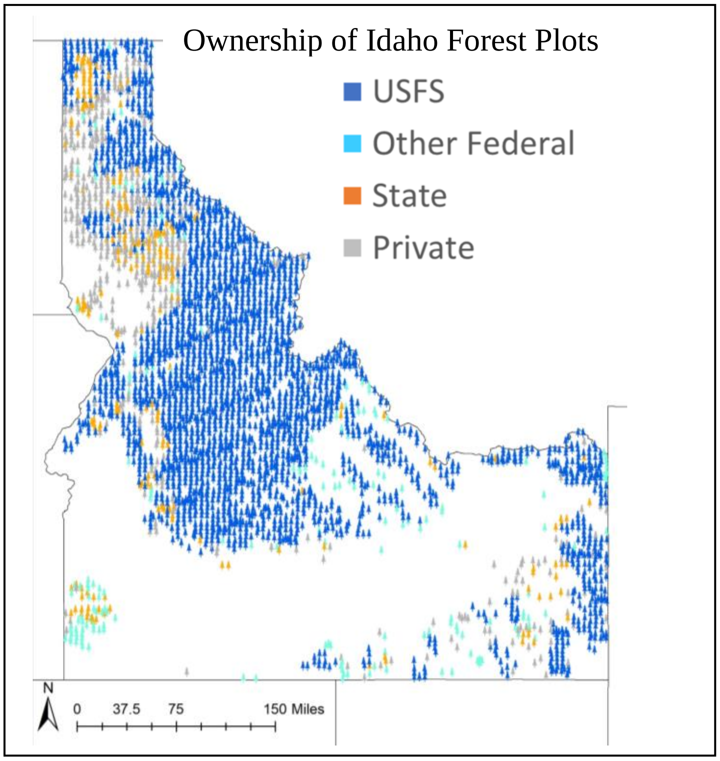
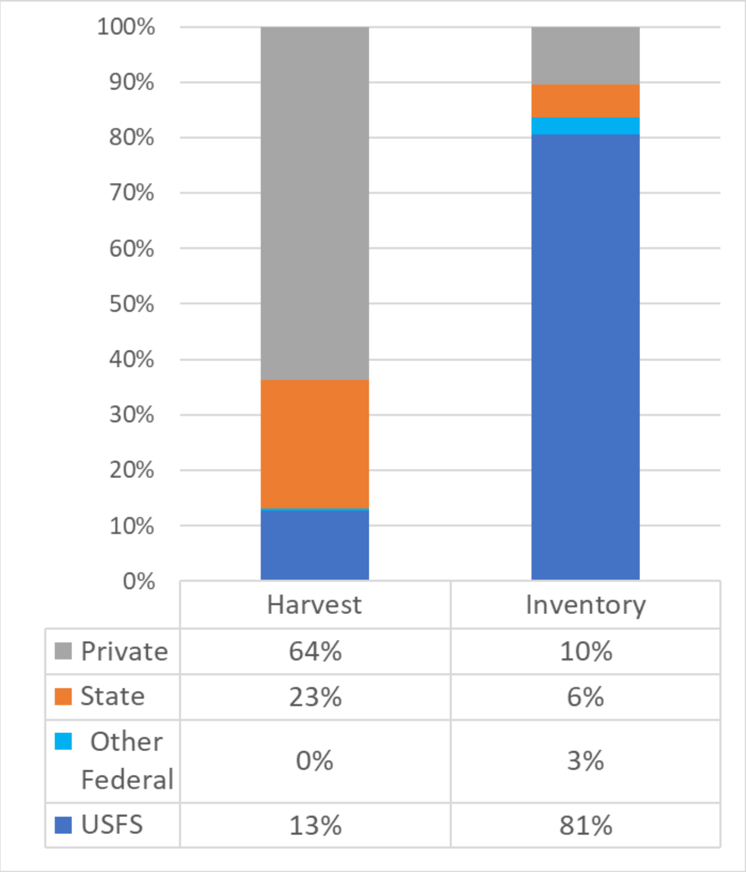


Figure 2. Ownership of Idaho forest plots (FIA sample plots from 2010 to 2019) (data source: USDA Forest Service, 2021).

Forest Harvest and Inventory Levels in Idaho



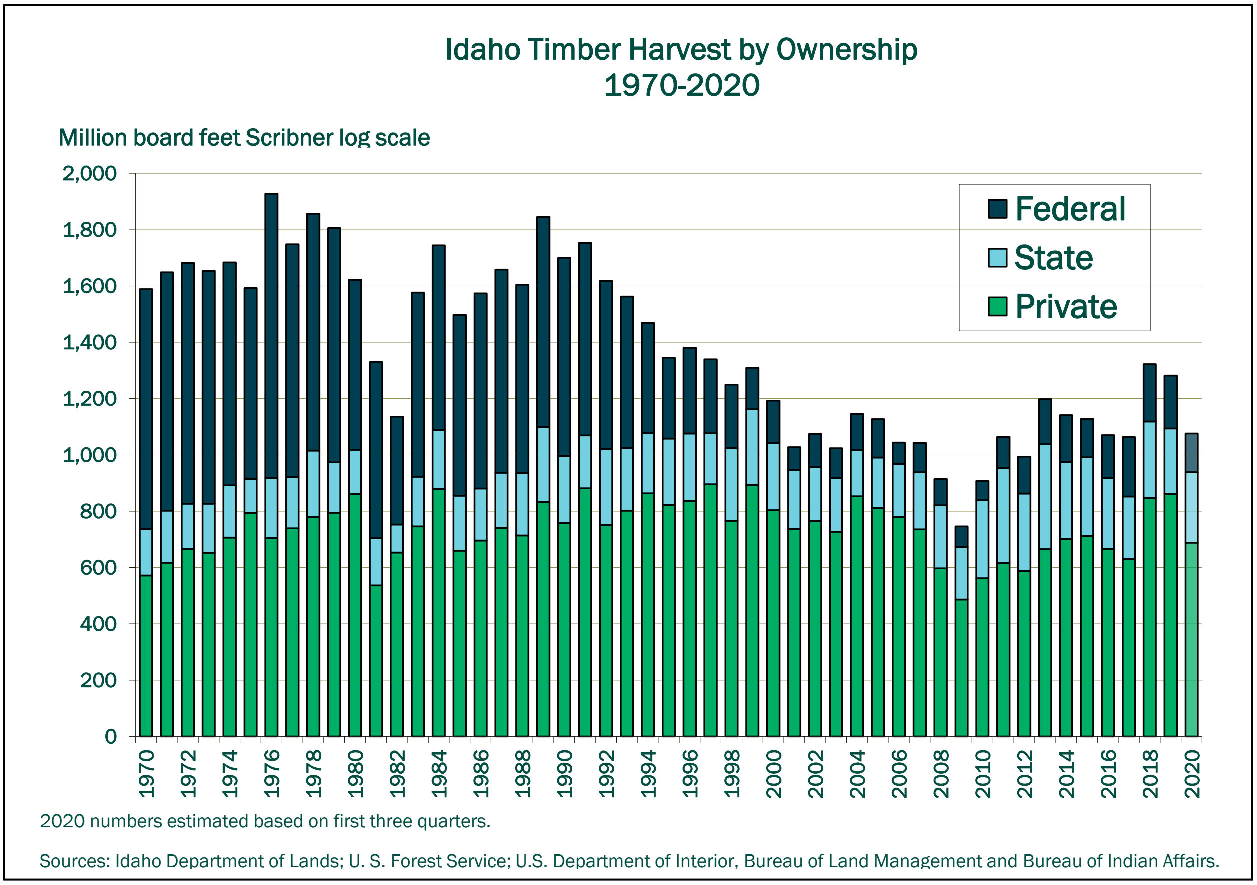
	Harvest	Inventory
■ Private	64%	10%
■ State	23%	6%
■ Other Federal	0%	3%
■ USFS	13%	81%

Figure 3. Harvest and inventory levels by owner type (2019) (data source: USDA Forest Service, 2021).

Forest management and timber harvest provide a range of economic contributions to Idaho's economy. The jobs and coupled labor income and revenue associated with growing, harvesting, hauling, and processing at forest products facilities are important to Idaho's rural economy. This includes not only those directly involved in the forest supply chain, but also a wide range of supporting (indirect) contributions provided by harvesting and manufacturing equipment and home sales and food to workers and their families (Policy Analysis Group, 2021). In 2020, the combined forest products industry direct and indirect employment was 31,414 persons (about 3% of state employment), contributing $2.4 billion (about 4%) to the gross state product (GSP) (Policy Analysis Group, 2019; 2021).

2. Recent trends

While it is important to understand current conditions to evaluate risk associated with climate change, it is also important to evaluate recent changes in the forests of Idaho. This report will illustrate some of these changes by focusing on removals and stocks. In the western U.S., it is difficult to understand forest conditions without considering reductions in federal harvest during the 1990s when the Endangered Species Act shifted harvesting practices. Figure 4 shows harvest by ownership type over the last 50 years. The 1970-2020 timeframe covers three distinct eras with respect to USFS harvesting. In the 1970-1989 time period, the USFS harvest averaged 45% of the state total, never falling below 33.7% and reaching a high of 53.6%. This was followed by the 1990-1999 period, in which the USFS harvest share fell from 41.4% to 11.3%. In the two decades since then, the USFS harvest share has averaged 11.9% of the state total, reaching as low as 7.2%, but never more than 19.9%.



2020 numbers estimated based on first three quarters.

Sources: Idaho Department of Lands; U. S. Forest Service; U.S. Department of Interior, Bureau of Land Management and Bureau of Indian Affairs.

Figure 4. Idaho timber harvest by ownership, 1970-2020 (Policy Analysis Group, 2021).

Forest carbon trends

Deciphering trends in Idaho's forest carbon stocks is difficult due to a number of factors. The first is that the national FIA inventory has changed methods multiple times, and the most recent approach takes a full 10 years for changes to be fully reflected in the data. To understand the data, one must first look at the methods. Prior to the commencement of the annual inventory in 2004, forest inventories needed to be assembled from multiple sources. The 1991 inventory (Brown and Chojnacky, 1996) was the last official measure, and it was comprised of two distinct data sources. All lands outside of National Forests were measured between 1990 and 1992, while the National Forest measurements ranged in date from 1974 to 1991. Since then, the National Forest data for the 1991 inventory estimate have been replaced with plot data measured from 1993 to 2002. There have been published reports that present statistics backdated as far as 1990 (Walters et al., 2021) using a simplistic smoothing technique described in Wear and Coulston (2015). However, the result is that reports that use these data (Forest Resources Association

(FRA), 2020) show a simple 30-year trend of declining stocks, and fail to recognize the management paradigm shift evident in Figure 4. The second part of understanding Idaho's FIA inventory relates to how the annual inventory was phased in. The inventory plots were divided into ten equal groups with one group to be visited each year between 2004 and 2013, and then each plot revisited on 10-year remeasurement cycle (Bechtold and Patterson, 2005). In Figure 5, the first 10-year initial measurement period is shaded in yellow, indicating low levels of precision in the initial years of the program. In fact, the 2005 plots were an outlier, with approximately 10% less volume than the 10-year average. This early outlier led to reports of rising stocks in the national reporting of 2007 (Smith et al., 2009), 2012 (Oswalt et al., 2014), and 2017 (Oswalt et al., 2019), which included data only through 2015 for Idaho. For this reason, data were downloaded directly (USDA Forest Service, 2021), and this report will focus on only the more recent annual inventory data to evaluate change.

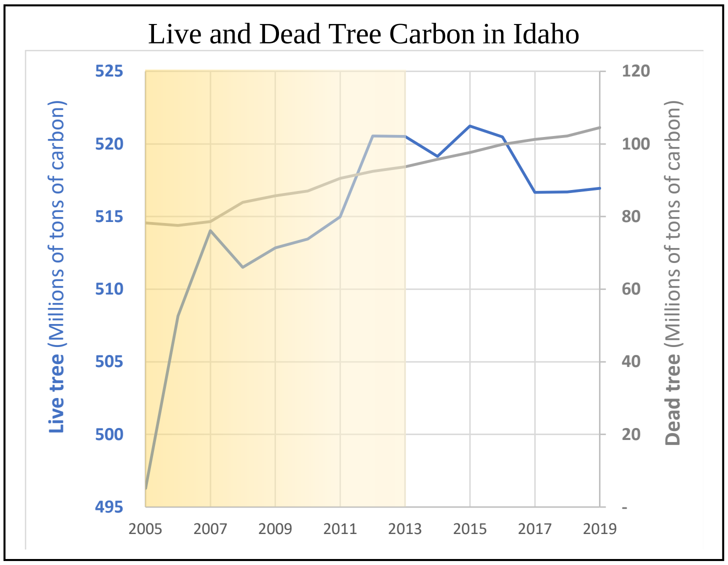


Figure 5. Idaho above and belowground live and dead tree carbon, 2005-2019. Shaded area indicates incomplete sample (USDA Forest Service, 2021).

Figure 5 shows the live and dead tree carbon stocks for the state of Idaho recorded since the FIA annual inventory began in 2004. As described above, a low outlier in 2005, the second year of the annual inventory, led to an appearance of rising live tree stocks in the shaded part of the graph prior to the full set of plots being measured. Since then, however, live tree carbon stocks have fallen by 3.5 million tons of carbon. Over this same time period, dead tree stocks have increased by 10.7 million tons of carbon. Figure 6, below, breaks these values out by forestland owner type for the years since the full 10-year sample size has been reached.

The left panel in Figure 6 shows the live tree carbon by owner and right panel in the figure the dead tree carbon by owner. In each case, the units for the USFS series are on the right, as they are substantially larger than the stocks on other federal, state, or private forest land in Idaho. The figure shows that the downward trend in live tree carbon and upward trend in dead tree carbon are largely driven by the USFS ownership. In general, private and state tree carbon stocks have been stable with respect to live trees, while dead tree stocks have fallen in each case. In aggregate, the most recent FIA inventory data indicate Idaho’s tree carbon stocks have been flat, with an increasing component of dead tree stocks.

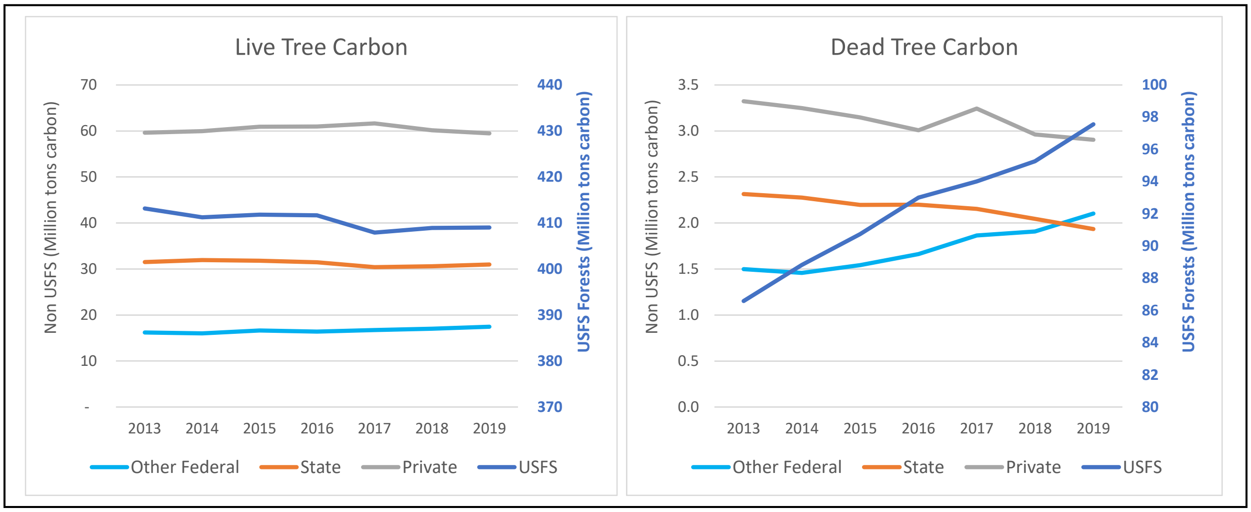


Figure 6. Idaho above and belowground live (left panel) and dead (right panel) tree carbon by forest owner, 2013-2019 (USDA Forest Service, 2021).

Forest disturbance

In addition to providing insight into forest carbon stock, the FIA inventory can be used to evaluate other aspects of change in Idaho’s forests. Change can be broadly grouped in two classes: forests disturbance and forest management. Figure 7 indicates where either forest disturbance (left panel) or forest management (right panel) was observed on FIA plots over the last ten years prior to measurement for the plots used in the 2019 FIA inventory. Forest disturbance locations are indicated with color plots: insect damage (green), disease (pink), wildfire (red), and other (black). In the Idaho panhandle, insects were the primary disturbing agent, while wildfire was most prevalent in the central mountainous region. The southern and eastern forests saw a broad mix of damage agents. Management was dominated by cutting and largely found on state and private lands of northern Idaho.

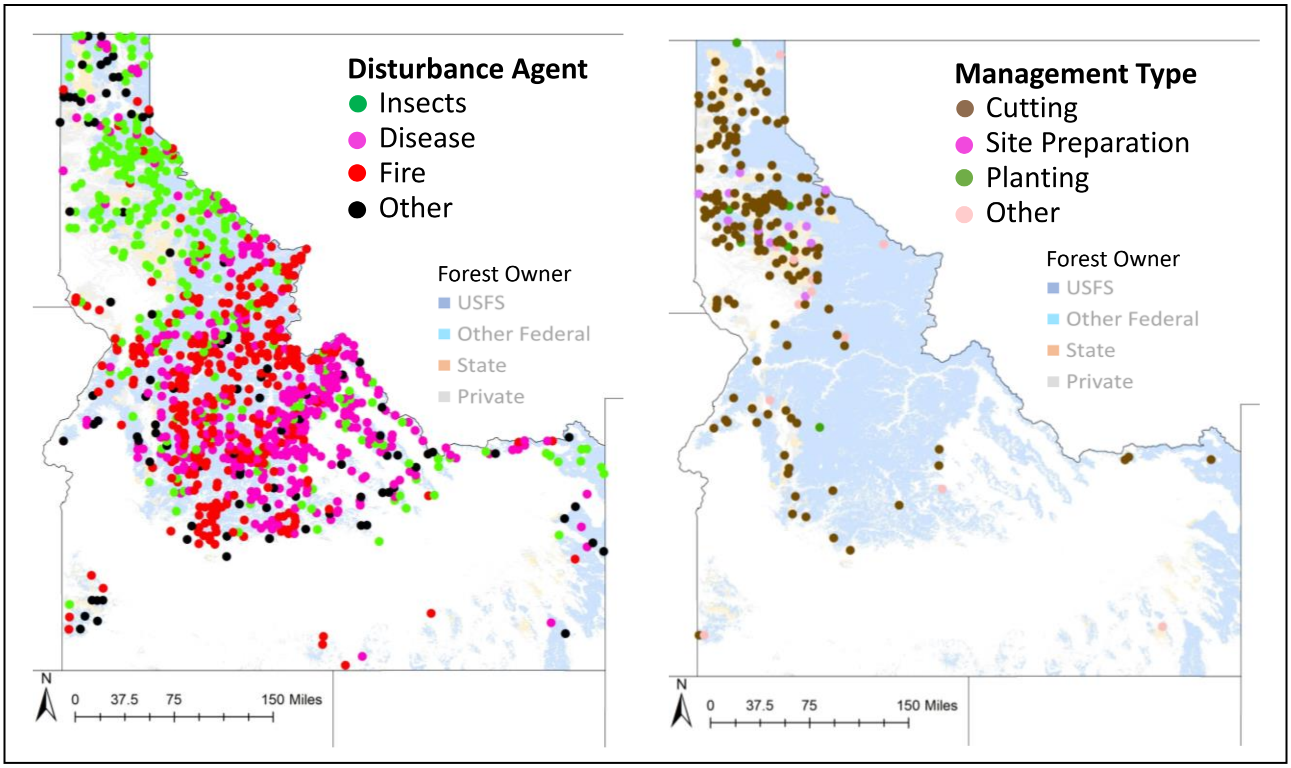
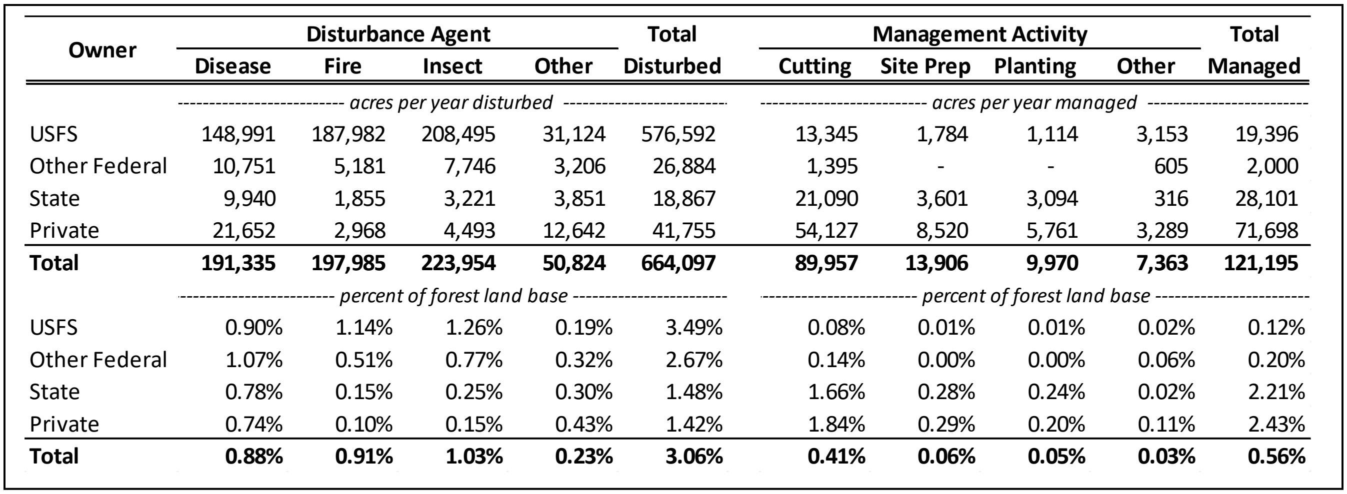


Figure 7. Locations of forest disturbance by damage agent in the left panel and forest management by management type in the right panel recorded on FIA plots in the 2019 inventory up to 10 years prior to measurement (USDA Forest Service, 2021).

Table 1 breaks the Figure 7 data by owner, and presents it in gross acreage and proportion of total forested acres in that ownership class. Table 1 shows that the 664,097 acres that experience disturbance through insects, disease, and wildfire vastly overshadow the 121,195 acres that undergo some sort of forest management activity.

As indicated in Figure 7, disturbances are the dominant agent of change on USFS and other federal land, while management is the dominant agent of change on state and private land. On USFS land, insects and wildfire are the largest disturbance agents, with all types of disturbance affecting 3.49% of the USFS forest land base on average over the last ten years. On state and private land, disease is the dominant agent, with less than 1.5% of the land affected. Control is dominated by cutting and mostly occurs on state and private land, which is to be expected, given the harvest levels indicated in Figure 4.



Owner	Disturbance Agent				Total	Management Activity				Total
	Disease	Fire	Insect	Other	Disturbed	Cutting	Site Prep	Planting	Other	Managed
	acres per year disturbed					*acres per year managed*				
USFS	148,991	187,982	208,495	31,124	576,592	13,345	1,784	1,114	3,153	19,396
Other Federal	10,751	5,181	7,746	3,206	26,884	1,395	-	-	605	2,000
State	9,940	1,855	3,221	3,851	18,867	21,090	3,601	3,094	316	28,101
Private	21,652	2,968	4,493	12,642	41,755	54,127	8,520	5,761	3,289	71,698
Total	**191,335**	**197,985**	**223,954**	**50,824**	**664,097**	**89,957**	**13,906**	**9,970**	**7,363**	**121,195**
	percent of forest land base					*percent of forest land base*				
USFS	0.90%	1.14%	1.26%	0.19%	3.49%	0.08%	0.01%	0.01%	0.02%	0.12%
Other Federal	1.07%	0.51%	0.77%	0.32%	2.67%	0.14%	0.00%	0.00%	0.06%	0.20%
State	0.78%	0.15%	0.25%	0.30%	1.48%	1.66%	0.28%	0.24%	0.02%	2.21%
Private	0.74%	0.10%	0.15%	0.43%	1.42%	1.84%	0.29%	0.20%	0.11%	2.43%
Total	**0.88%**	**0.91%**	**1.03%**	**0.23%**	**3.06%**	**0.41%**	**0.06%**	**0.05%**	**0.03%**	**0.56%**

Table 1. Disturbance agent (left panel) and management activity (right panel) recorded on FIA plots in Idaho in the ten years prior to measurement for the 2019 inventory by ownership group presented for both acreage and proportion of forested land (USDA Forest Service, 2021).

The last ten years of change in Idaho's forests indicates two distinctly different classes of forests in the state. State and private forests can be largely characterized as forests with stable live tree stocks and declining dead tree stocks in which the footprint of forest management is larger than that of natural disturbance. Conversely, federal forests tend to have declining live tree stocks and increasing dead tree stocks on a landscape where natural disturbance dominates the low levels of management activity. With a changing climate, management focus and resource characteristics will affect forest response.

3. How forests respond to climate change

Multiple aspects of the changing climate influence Idaho's forests. (See the assessment's Climate Report for more details about temperature, precipitation, snowpack, drought, etc.) Idaho has experienced warming by 1.8ºF in annual mean temperature over the last century, and projections indicate continued warming through 2100 by an additional 6-11ºF, depending on emissions scenario. Warming leads to longer potential growing seasons for trees, particularly in higher-elevation (energy-limited) forests (Klos et al., 2015). Warmer conditions will lead to a reduced snowpack, with more precipitation falling as rain instead of snow, thereby resulting in less water stored in snowpack. Warming also causes earlier snowmelt and greater evaporation and transpiration, leading to reduced soil moisture in summer. Because Idaho receives little precipitation in the summer growing season, warmer conditions exacerbate and extend the summer dry period that inhibits tree growth. During droughts, hotter conditions lead to greater stress on trees and can result in widespread tree mortality, often in conjunction with other disturbance agents (wildfires, insects) (Allen et al., 2015).

Observations of historical precipitation have indicated variability in trends (negative, no change, or positive) depending on season, location, and time period. Future projections suggest some increase (5-10%) in annual total precipitation by 2100, which may lead to greater snowpack at the higher elevations and partially offset snowpack loss from warming at lower elevations

(Figure 8). Important for tree growth, summer precipitation is expected to decrease by around 10% (with high uncertainty) (Figure 8).

Temperature and moisture combine to affect tree growth and species distributions through atmospheric and soil moisture (Littell et al., 2010). Tree stress that may lead to reduced growth and/or mortality can be induced by a very dry atmosphere (which is a function of both air temperature and humidity). Soil moisture is affected by total precipitation and its seasonal distribution, as well as by temperature through effects on evaporation and transpiration. These stressful conditions are enhanced by warming (Breshears et al., 2005).

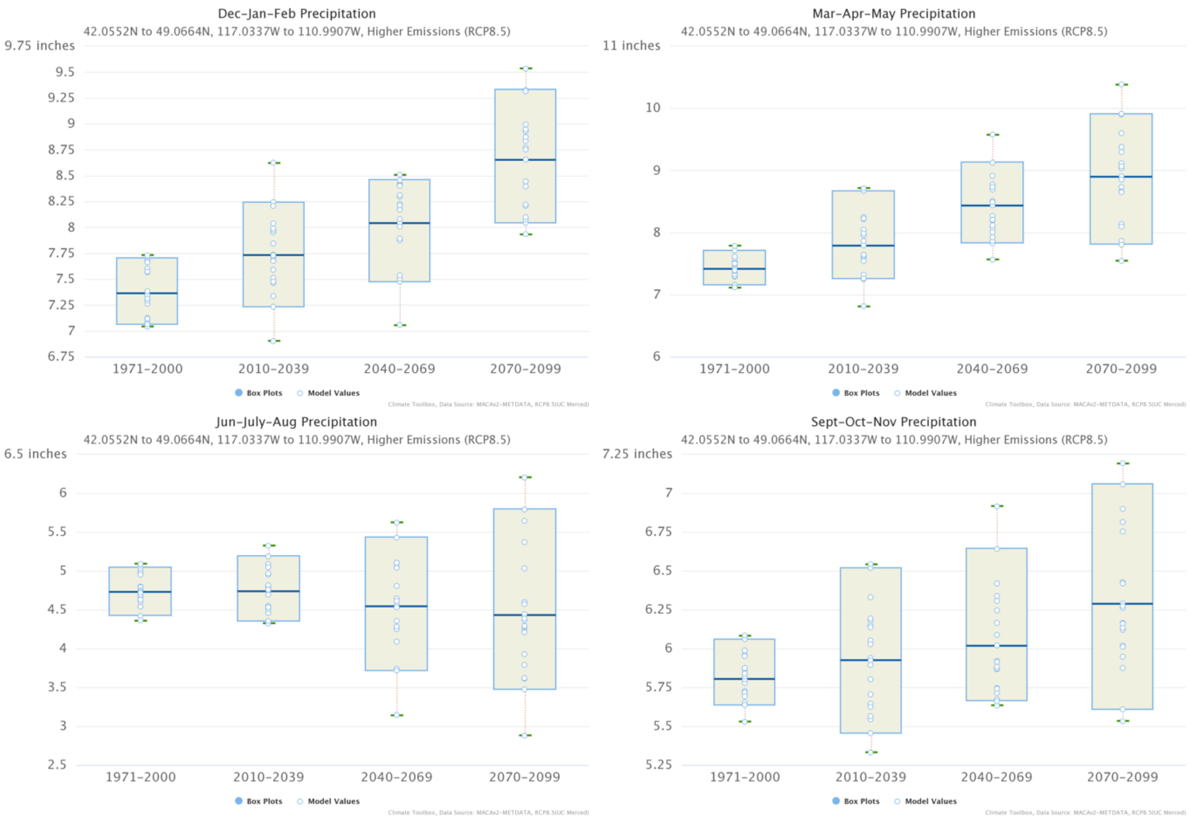


Figure 8. Projections of seasonal precipitation change (inches) in Idaho (using higher (RCP8.5) emissions scenario). Changes are smaller for results using RCP4.5 (not presented in this figure).[1] From climatetoolbox.org (downloaded June 9, 2021).

Theoretical, experimental, and observational studies have shown that increases in atmospheric CO_2 stimulate plant growth and reduce moisture stress in water-limited situations through more efficient use of existing water (Walker et al., 2020). Whether the observed and expected continued increase in CO_2 actually produce enhanced tree growth in Idaho's forests depends on

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[1] Representative Concentration Pathways (RCPs) are emission scenarios. RCP4.5 is a moderate-warming scenario and RCP8.5 is a high-warming scenario. Details provided in the assessment's Climate Report.

multiple factors that include soil fertility and moisture stress, and the net response is currently unknown.

Climate change can also act on forests indirectly through disturbances (Seidl et al., 2017). Warmer, drier conditions are more conducive to wildfires (Abatzoglou and Williams, 2016) and bark beetle outbreaks (Bentz et al., 2010), two disturbance agents that affect large areas of Idaho's forests (Hicke et al., 2016). Forest pathogens (which cause tree diseases) benefit from warmer conditions and greater host stress; some pathogens prefer wetter conditions, others drier conditions (Sturrock et al., 2011).

4. Climate change impacts to forests

Forest types, tree species, and tree growth

Climate change is generally expected to cause tree species to move poleward and upward in elevation in response to warming (Webb III and Bartlein, 1992; Settele et al., 2015). Dominant tree species are often ordered along an elevational gradient based on thermal and moisture conditions (Daubenmire, 1966; Cooper et al., 1991) (Figure 9). Theoretical understanding suggests that with warming, tree species ranges are expected to advance upslope to currently cooler conditions (Rosenzweig et al., 2007). At the lowest elevation of a tree species' range, which is typically the warmest and driest location within the range, the presence or abundance of that species may decline because of additional stress, and new species more suitable for warmer conditions (currently located downslope) may increase in number. At the highest elevation within a range, the species may expand its range upward as the climate warms. At the lowest forested elevations, trees may be replaced by grasslands or shrublands with warming. Species at the tops of mountains may experience reductions in range or abundance because of a lack of new, more suitable habitat into which to disperse. Although these general patterns are expected, there is likely to be variability among species (e.g., Prasad et al., 2020).

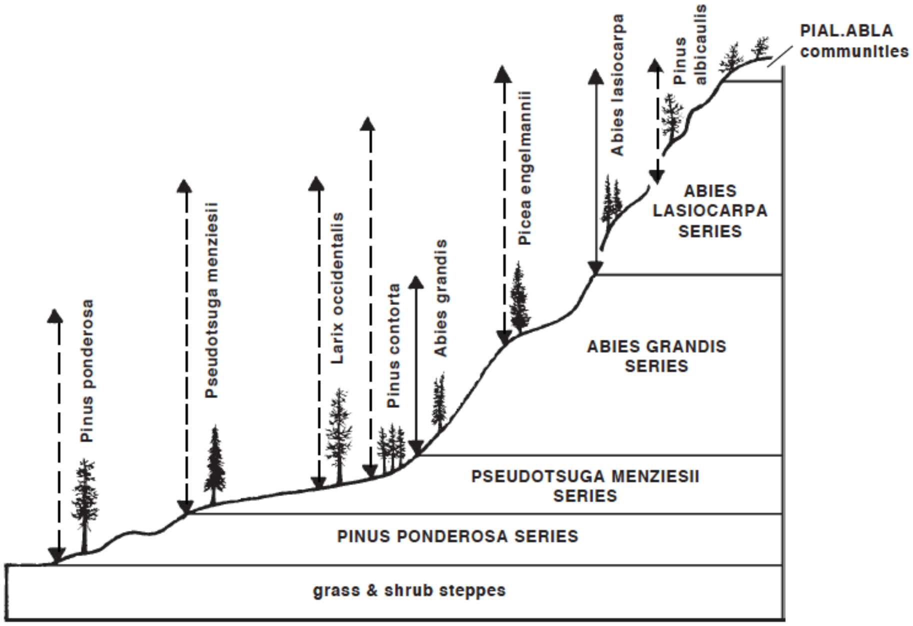


Figure 9. Example of elevational distribution of coniferous tree species in northern Idaho. Figure from Cooper et al. (1991).

Direct responses of tree growth and productivity to climate change vary by species and location. In general, at higher elevations, tree species are limited by energy availability, and these species will benefit from some warming through a longer and warmer growing season (Halofsky et al., 2018). In contrast, at lower elevations, tree species, such as Douglas-fir, are limited by water availability; therefore warming and drying in summer (as projected for Idaho) will reduce tree growth (Littell et al., 2010).

The expected response of individual tree species to climate change varies, with some species benefiting, other species persisting, and still other species affected adversely (Halofsky et al., 2018). Substantial uncertainty exists about responses (Halofsky et al., 2018). Many tree species may reduce their range in Idaho in the coming decades (Rehfeldt et al., 2006; Crookston et al., 2010; Littell et al., 2010; Halofsky et al., 2018). Important timber species, such as Douglas-fir and western larch, are projected to experience significant range contraction or shifts of climate suitability to different locations across the state, whereas high-elevation species, such as whitebark pine, may disappear from Idaho (Figure 10) (Crookston et al., 2010). Other tree species that favor drier conditions, such as Gambel's oak, may expand their range or increase in abundance (Rehfeldt et al., 2006; Halofsky et al., 2018).

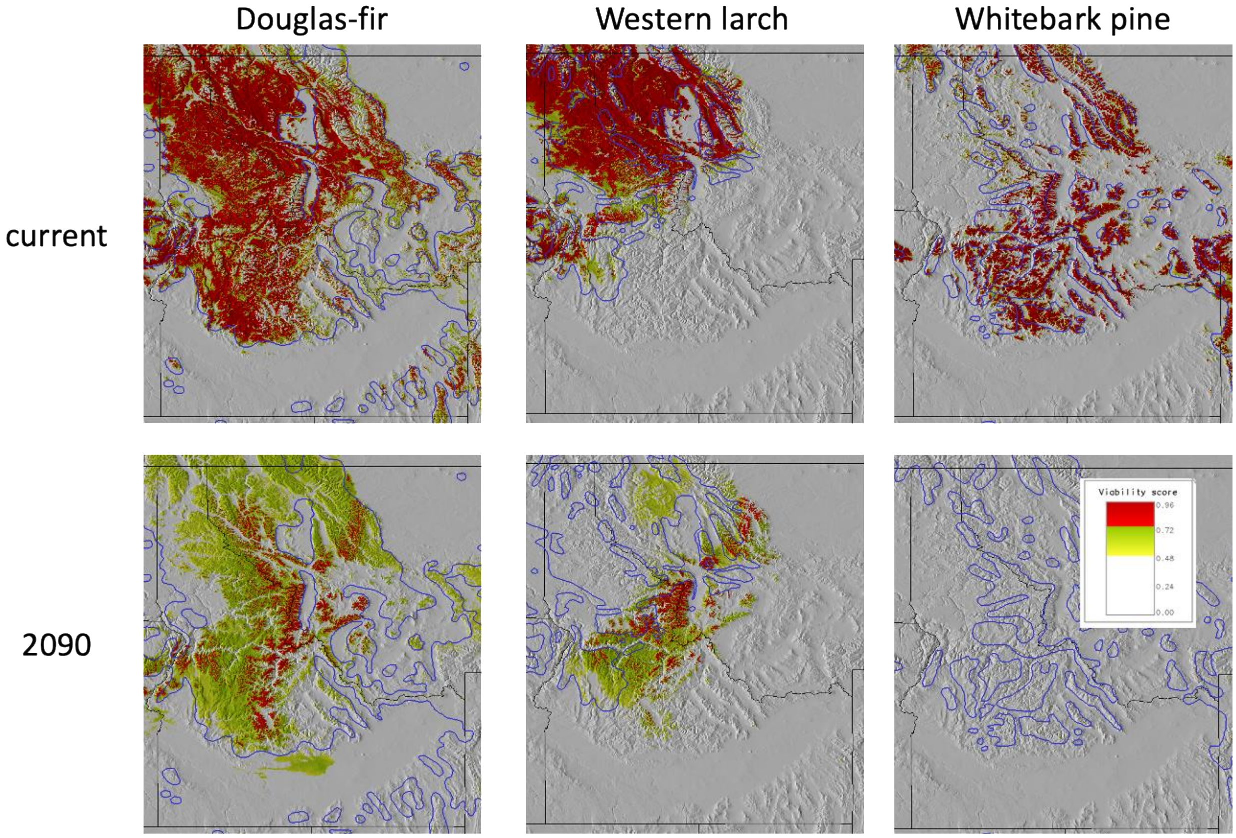
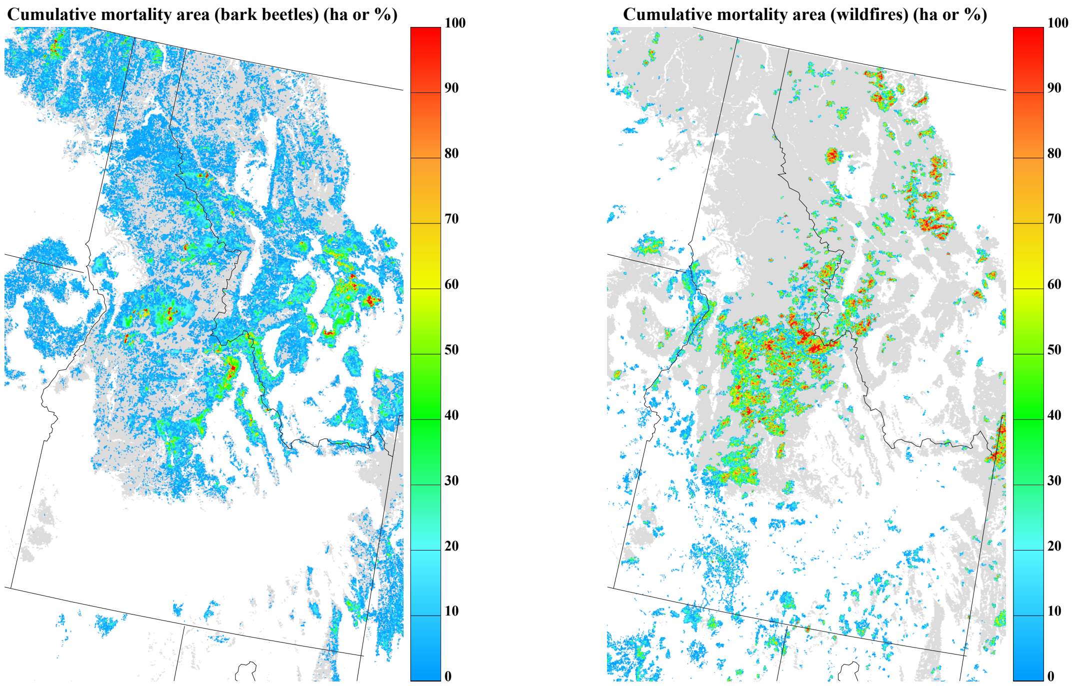


Figure 10. Current (top row) and projected (2090, bottom row) locations of climate suitability of three coniferous tree species (columns) in Idaho produced using statistical modeling. Future projections estimated with a high emissions scenario (A2) and the Canadian Center for Climate Modeling and Analysis climate model (CGCM-3). Viability scores are plotted and range from 0 to 1, with 0 indicating lack of climate suitability and 1 indicating high climate suitability. Red indicates high climate suitability areas for each species, green moderate suitability, and gray low suitability. Figures from Crookston et al. (2010), downloaded from charcoal.cnre.vt.edu/climate.

Current and projected warming rates greatly exceed that experienced by ecosystems in the past (Diffenbaugh and Field, 2013). The success of species (including tree species) to shift their range rapidly enough to keep up with this warming depends not only on the warming trend, but also on how rapidly temperature changes across a landscape (IPCC, 2014). The latter effect depends on the equator-to-pole gradient, as well as on topography. Because mountainous terrain typically provides cooler conditions as elevation increases, species have to shift less in the horizontal direction to keep up with warming (Loarie et al., 2009). Thus, tree species in Idaho may adapt better to future climate change through range shifts than other, flatter locations.

Forest disturbances

Natural forest disturbances, including wildfire, insect and pathogen outbreaks, and severe drought, are significant in Idaho. In recent decades, wildfires and bark beetle outbreaks have killed trees across 1.2-2.4 million and 1.5 million acres, respectively, in Idaho's forests (Hicke et al., 2016) (Figure 11), with mortality continuing today (Idaho Department of Lands, 2019). Because seedlings have narrower tolerances of environmental stresses compared with mature trees (Jackson et al., 2009), disturbances that kill trees accelerate the impacts of climate change on tree species distributions. Current and future climates that are tolerated by mature, established trees may be outside of seedling tolerances, thereby reducing seedling survival and potentially leading to shifts in tree species composition or changes to non-forest vegetation type (shrubland or grassland). These changes have occurred in lower-elevation, drier forest types that already experienced heat and moisture stress, leading to range contraction in these areas, and such responses are expected to continue (Haffey et al., 2018; Halofsky et al., 2018; Parks et al., 2019; Halofsky et al., 2020). In northern Idaho, these "trailing edge" areas are projected to contract by 13% by mid-century, and in central Idaho, by 15% (Parks et al., 2019). Furthermore, the presence of mature trees facilitates seedling establishment; the potential for greater forest disturbances from future climate change may therefore hinder regeneration (Dobrowski et al., 2015).


Cumulative mortality area (bark beetles) (ha or %)

Cumulative mortality area (wildfires) (ha or %)

Figure 11. Mortality area (area occupied by killed trees; different than "affected area" reported by USFS or burned area) caused by bark beetle outbreaks during 1997-2019 (left) (Hicke et al., 2020) and wildfires during 1984-2012 (right) (Hicke et al., 2016) in Idaho. Colors indicate mortality area in ha, equivalent (because of the 1-km grid cells) to percentage of grid cell.

Climate change has increased the area burned by forest fires in recent years in the western U.S., and is expected to increase burned area in the future. Warming since the mid-1980s has led to longer wildfire seasons and drier fuels (Westerling, 2016; Halofsky et al., 2020). One study found that anthropogenic climate change was responsible for about 50% of the burned area in the western U.S. during 1984-2015 (Abatzoglou and Williams, 2016). Reduced summer precipitation also contributed to this increase (Holden et al., 2018). Increased temperatures have lengthened wildfire seasons (Westerling, 2016), leading to more chances for wildfire ignition and spread, and have reduced fuel moisture (creating more flammable fuels) (Abatzoglou et al., 2019). Warmer and drier conditions during 1985-2017 have led to greater area burned at high severity in the western U.S. (Parks and Abatzoglou, 2020). Future climate change is expected to lead to more favorable conditions for wildfires (IPCC, 2021), and to increase wildfire activity throughout the Pacific Northwest (Halofsky et al., 2020). Burned area in Idaho's forests is projected to increase in the coming decades in response to future climate change, sometimes substantially (depending on climate model and location) (Littell et al., 2018).

Wildfires can have significant consequences for forest ecosystems. Severe wildfires may lead to substantially modified forests in terms of age, density, and composition (Halofsky et al., 2018). Recent warmer and drier conditions have reduced tree seedling establishment following wildfire, challenging the recovery of forests (Stevens-Rumann et al., 2018; Davis et al., 2019). The expected increase in future wildfire activity caused by future climate change will lead to reduced forest recovery as wildfires burn forests more frequently (Turner et al., 2019). Warming and greater moisture stress will continue to reduce seedling survival in some forest types (Rodman et al., 2020), potentially leading to conversion of forests to other vegetation types (Haffey et al., 2018; Parks et al., 2019; Stevens-Rumann and Morgan, 2019; Coop et al., 2020; Halofsky et al., 2020).

States provide funding for wildfire suppression on state and private lands. Idaho's funding varies substantially depending on year, partially as a result of variability in burned area (Cook and Becker, 2017). Of the time period studied (2005-2015), the recent extreme wildfire years in 2014 and 2015 cost Idaho $30 and $80 million, respectively (Cook and Becker, 2017).

The costs of wildfire suppression are expected to increase greatly through 2100, and smoke from wildfires is expected to increase health impacts. See the assessment's Health Report and Smoke Report for more information regarding health and economic impacts from smoke.

Insects and pathogens are significant disturbances in Idaho's forests, damaging or killing large areas of forest. Bark beetles are widespread disturbance agents, and during 1997-2012, mortality area in Idaho's forests was 2 million acres, or about 7% (Hicke et al., 2016), with additional mortality since 2012 (Idaho Department of Lands, 2019). Projected warming is expected to increase the conditions favorable for these outbreaks through reduced killing temperatures in winter, warmer and therefore more favorable conditions for beetle development and population growth, and enhanced drought stress of host trees, including species common to Idaho, such as Douglas-fir, lodgepole pine, and subalpine fir (Bentz et al., 2010; Buotte et al., 2017). Some defoliating insects may benefit from drought (Kolb et al., 2016), including western spruce budworm (Xu et al., 2019) (important in Idaho because of the extent of damage), thereby leading to greater impacts on Idaho's forests. Responses of forest pathogens to future climate change varies among pathogens, but some will benefit from warmer, drier conditions (Sturrock et al., 2011; Kolb et al., 2016).

Drought can reduce tree growth and cause widespread tree mortality, often in conjunction with other forest disturbances (wildfire, insect outbreaks) (Anderegg et al., 2015). Dry soil and atmospheric conditions cause trees to shut down photosynthesis, and therefore transpiration, to conserve water and avoid death. These growth reductions decrease tree defensive capacity against insect and pathogen attack. Significant growth reductions (Schwalm et al., 2012) and tree mortality (Hicke et al., 2020) occurred in the forests of the western U.S. associated with a severe drought during 2000-2004. Future climate change is expected to lead to greater tree mortality from heat and drought (Allen et al., 2015). The time ecosystems need to recover from drought has increased during the last century (Schwalm et al., 2017), and with expected increases in drought frequency, Idaho's forests may be challenged to maintain existing growth levels.

Ecosystem services of forests

Impacts to future timber harvest from the direct effects of future climate change will be variable, following from the variability among species and locations of responses of tree growth, as well as potential range shifts and from the spatial variability of climate change and resulting future climate (e.g., lower versus upper elevation). As noted above, some tree species important for timber may benefit in some locations from future climate change; other species will experience reduced growth from additional warming and moisture stress. All tree species are likely to experience more frequent, severe, and extensive disturbances (wildfires, insect and pathogen outbreaks, and drought) from future climate change (Vose et al., 2018), and the resulting growth reduction and mortality will adversely affect timber yields.

Forests provide other ecosystem services. Forests offer recreational opportunities for people, including hunting, fishing, hiking, camping, and snow sports (see the assessment's Recreation and Tourism Report). Climate change that alters forest existence; structure (e.g., age, size, species); and function (e.g., productivity) may therefore affect these services. A notable example is the recreational use of disturbed forests. Trees killed by wildfires and insect outbreaks pose risks for people in the form of falling snags, trail and road closures, and affected campgrounds. Furthermore, as a warming and drying climate increases the risk of wildfire, public and private managers may close forests to recreational use to minimize the chance of a wildfire. Other plant and animal species use forests for habitat, food, and cover. Forests also provide a climate service by sequestering carbon, described in Section 5.

5. Opportunities and considerations for mitigation and adaptation and implications for Idaho's economy

Mitigation

Forests are important components in the cycling of carbon between ecosystems and the atmosphere (Janowiak et al., 2017), and can play a major role in limiting future greenhouse gas increases in the atmosphere (mitigation). Forests hold the most potential of all "natural climate solutions" (solutions for reducing future climate change using natural ecosystems), both globally (Griscom et al., 2017) and in the U.S. (Fargione et al., 2018). Tree growth removes carbon from the atmosphere and sequesters a portion in stems, branches, leaves, and roots. Forest disturbances can release some of that carbon back to the atmosphere, either rapidly through combustion or, as for most tree carbon, over years to decades through decomposition. During this time, the next generation of trees may be regrowing, thereby offsetting or even outweighing this release. Whether a forest is a net source or sink of carbon (is it releasing carbon to the atmosphere or taking up carbon?) depends on a number of factors that affect both the growth and decomposition of dead organic matter, including climate, topography, soil fertility, tree species, and time since last disturbance.

The 1.7 billion metric tonnes of carbon stored in Idaho's forest ecosystem represent 3% of the national forest ecosystem stocks (Walters et al., 2021). Idaho's forests have recently experienced relatively high rates of disturbance (wildfires and bark beetle outbreaks) among western states (Hicke et al., 2016), which has led it to be one of nine intermountain states experiencing net emissions as opposed to sequestration of carbon (Walters et al., 2021).

Opportunities to use forests for climate mitigation include keeping forests on the landscape, expanding forest area, and enhancing the carbon sequestered in those forests (Janowiak et al., 2017; Fargione et al., 2018). Avoiding deforestation, or the conversion of forest land to non-forest land (e.g., urban, agriculture), will keep carbon associated with forest ecosystems from entering the atmosphere. Decreasing timber harvest intensity or extending rotation lengths may keep carbon sequestered in forests and out of the atmosphere. However, greater sequestration can often be realized if timber harvest results in wood products that are used in ways that extend the lifetime of wood beyond natural lengths of time (i.e., delay decomposition), such as in long-lived building materials, there is a net gain of carbon as the newly established trees replace the harvested ones.

Another mitigation option is to allow locations that can support forests naturally to regain carbon through conversion back to forest land (reforestation). These locations may have been partially or completely harvested, cleared for agricultural purposes, or burned or otherwise affected by disturbances. About 40% of the area of Idaho's forests is non-stocked or poorly stocked (<35% of forestland is occupied by trees), suggesting significant capacity to sequester carbon (Domke et al., 2020). Three-quarters of this is federal land, with about 5-8% private land, and about 17-20% state land (Domke et al., 2020). Managing forests to increase carbon stocks may conflict with other objectives. For instance, a management option to limit forest disturbances (wildfires, insect outbreaks) is to thin forests. Such action reduces carbon stocks in the short-term, but may increase carbon stocks in the long-term by avoiding widespread, severe disturbances (see below).

Additional options are to increase tree growth or lengthen harvest intervals, thereby increasing carbon stocks (McKinley et al., 2011; Fargione et al., 2018). Management activities that assist with both options include planting seedlings and considering species and populations that may thrive better in future climates; fertilizing; limiting competing and/or invasive non-native plant and animal species; and minimizing disturbances (McKinley et al., 2011; Fargione et al., 2018).

Minimizing severe natural forest disturbances will reduce carbon losses and decrease the release of forest carbon to the atmosphere. In Idaho, these disturbances are primarily wildfire, drought, and insect and pathogen outbreaks. Actions that reduce fuels, such as prescribed low-severity burning or thinning, may decrease the probability of future high-severity wildfires that kill trees, thereby resulting in greater carbon in forests (Loudermilk et al., 2017; McCauley et al., 2019). Thinning forests will reduce resource competition, including water, thus increasing a tree's capability to withstand drought or biotic agent attack. However, the removed trees also will release carbon back to the atmosphere, implying potential tradeoffs between limiting severe disturbances and sequestering carbon (Loudermilk et al., 2017; McCauley et al., 2019). Allowing or promoting a diverse forest in terms of age, size, and species composition can limit the extent and severity of disturbances.

Afforestation is the process of planting forests in locations that cannot support forests without assistance or management (i.e., in places that do not naturally support forests). Often these areas are too dry for trees, necessitating irrigation. Over 4 million acres have been identified in Idaho alone where such opportunities exist (Cook-Patton et al., 2020). Because of this required assistance, afforestation may introduce a set of potentially adverse effects, such as groundwater pumping, fertilization, or land-use change (McKinley et al., 2011). To achieve such a level of scale would also require substantial investment to bolster existing seed supply and nurseries, as well as post-planting costs (Fargione et al., 2021). Finally, recent research has questioned whether the radiative forcing effects of the change in surface albedo would negate any potential carbon sequestration mitigating effects of afforestation in the region and lead toward net warming (Mykleby et al., 2017; Williams et al., 2021).

Forest carbon offset programs, such as the Compliance Offsets Program[2] administered by the California Air Resources Board (CARB), provide an incentive for forest lands to sequester additional carbon through forest management, thereby earning income. Many corporations have voluntarily signed commitments to measure, report, and reduce greenhouse gases through Science-based Targets (over 1,617 companies listed at sciencebasedtargets.org), the Climate Pledge (110 companies at www.theclimatepledge.com), or Transform to Net Zero (10 companies at transformtonetzero.org), and those efforts often include offsets as part of the mitigation strategy. Idaho forests are not part of offset programs at present.

Forests can also mitigate future climate change by providing biofuel that substitutes for the burning of fossil fuels, although the carbon benefits are still debated (Booth et al., 2020). For example, the University of Idaho uses wood chips from waste streams of local wood products manufacturers to power its steam plant. Currently, the national use of wood for generating energy is a small proportion (2.3%) of the total amount consumed in the U.S. (U.S. Energy Information Administration, 2021).

Objectives for using forests to mitigate future climate change may be considered along with other appropriate objectives for Idaho's forests. For instance, other important objectives may include timber production, recreational use, species protection, and habitat.

Adaptation

Adaptation actions are those that minimize the negative effects of climate change. Forests can adapt naturally to climate change through range shifts or modifications of abundance or productivity. A range of management responses exist to address climate change impacts on forests (Millar et al., 2007; Stephenson and Millar, 2012; Lipton et al., 2018; Vose et al., 2018). Forests can be left alone, or actions can be minimal in extent and effort; these options may be applicable to wilderness areas or if time, effort, and funds limit action. Enhancing a forest's ability to absorb climate change-related stress may be possible through, for instance, minimizing other stressors, such as invasive species or thinning forests to decrease competition for resources such as water. More active management activities can assist tree species by minimizing the extent and severity of climate-influenced disturbances or irrigating selected individual, high-value trees. These types of options may be only available for a short period into the future, depending on the rate of climate change, and therefore a longer-term set of options may need to be considered that facilitate forest change. Examples include assisted migration (aiding range shifts by planting trees of a threatened species in locations whose future climate is more suitable) or, in a particular location of interest, facilitating establishment of new tree species better suited to a location after a severe wildfire or drought.

In addition, forest management can be used in adaptation actions to minimize adverse effects of climate change on other systems. In forest ecosystems, thinning and prescribed burning can

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[2] The Compliance Offsets Program administered by CARB, the largest regulatory forest offset program in the U.S., consists of 149 projects that have been awarded a combined 182 million tons of offsets. CARB issues Offset Credits to qualifying projects that reduce or sequester GHG. Compliance offsets are tradable credits that represent verified GHG emissions reductions or removal enhancements.

reduce wildfire extent and severity and therefore limit spread into non-forest ecosystems, including urban or suburban areas (Schoennagel et al., 2017). Riparian buffer strips reduce stream temperature and facilitate maintenance of aquatic ecosystem biodiversity (Johnson and Almlöf, 2016). Reducing tree density may increase snow duration (Lundquist et al., 2013) and increase meltwater volume (Harpold et al., 2020).

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