Climate Change

Key Points

- Net carbon storage would increase under all alternatives and the Proposed RMP, with the largest increase under Alternative D and the least increase under Alternative C.
- Annual greenhouse gas emissions associated with BLM-administered lands would increase under all alternatives and the Proposed RMP, with the largest increase under Alternative C and the least increase under Alternative D. Annual greenhouse gas emissions associated with BLM-administered lands would remain less than 1 percent of the 2010 Statewide greenhouse gas emissions.
- Climate change provides uncertainty that reserves will function as intended and that planned timber harvest levels can be attained, with the uncertainty increasing over time.
- Active management would provide opportunities to implement climate change adaptive strategies and potentially reduce social and ecological disruptions arising from warming and drying conditions.

Summary of Notable Changes from the Draft RMP/EIS

The BLM has refined the calculations of carbon storage and greenhouse gas emissions, including the following:

- Removing the acreage in roads and water from the estimated carbon stored in soils
- Correcting the number of acres affected by wildfire
- Correcting the number of acres of expected underburning/broadcast burning
- Removing unmodeled forest as a category and replacing it with non-forest estimates
- Correcting the animal unit month values for the No Action alternative in the estimated greenhouse gas emissions

These refinements in the calculations alter the absolute values in these calculations, but do not alter the relative outcomes of the alternatives and the Proposed RMP or the overall analytical conclusions.

The BLM has corrected the values in **Table 3-13** for carbon density; the Draft RMP/EIS erroneously provided carbon density data in terms of Mg/ha instead of Mg/acre.

The BLM has added discussion and estimation of the effects of hazardous fuels treatments on net carbon storage and has expanded the discussion under Issues 1 and 2 of the cumulative effect of carbon storage and greenhouse gas emissions in the context of other actions.

Issue 1

What would be the effects of BLM forest management on long-term net carbon storage?

Summary of Analytical Methods

The BLM estimated changes in the amount of carbon stored on the landscape in vegetation and soils, and in harvested wood products. This analysis accounts for the removal of carbon through wildfire, prescribed fire, and timber harvesting and the addition of carbon through vegetation growth. As such, this analysis estimates changes in the net amount of carbon stored under the different alternatives and the Proposed RMP.

The BLM estimated net carbon storage on BLM-administered lands in the planning area by first estimating the amount of biomass on these lands and converting that to the carbon in live trees, standing and downed dead wood, understory vegetation, litter and duff, and in the upper 1 meter (3.3 ft.) of soil, except where noted. The Planning Criteria provides detailed information on analytical assumptions, methods and techniques, and geographic and temporal scales, which is incorporated here by reference (USDI BLM 214, pp. 36–38). The volume harvested, whether part of the Harvest Land Base or reserves, drives the variation in carbon storage under the different alternatives and the Proposed RMP.

The BLM assumed the following categories to be constant across all alternatives and the Proposed RMP:

- Carbon stored in soils
- Carbon stored in non-forested lands
- Carbon loss from wildland fire

The BLM assumed no carbon is stored under roads or in water, and reduced the landbase used for net carbon storage estimation accordingly. Although there is some carbon storage under roads or in water, there is no data available to quantify this storage. Furthermore, the carbon storage would not measurably differ among the alternatives and the Proposed RMP over time, and thus would not alter the relative outcomes under the alternatives or the Proposed RMP.

Although the BLM used much of the analytical approach described in the Planning Criteria, the BLM modified the data source for aboveground carbon based on the actual outputs from the Woodstock model. Instead of using stand structure as the basis for estimating the amount of above-ground carbon, as described in the Planning Criteria, the BLM used approximate stand age in combination with the information available through the Carbon OnLine Estimator version 3.0 (COLE 3.0 2015) to estimate the amount of carbon stored in standing and downed dead wood, understory vegetation, the forest floor (litter and duff) and soil. Instead of using only two regions, the BLM filtered the COLE outputs to report carbon storage for all Federal lands in the counties in which the majority of each BLM district occurs. For example, the BLM used all Federal lands in Coos and Curry Counties as the basis for estimates for Coos Bay District. This approach allowed for estimates that were more refined and better captured the variability in carbon stored than using the two regions. The BLM used all Federal lands instead of all lands, as the data for private lands tended to be skewed towards younger age classes than are typically present on the Federal lands. Furthermore, the data for only BLM-administered lands lacked a sufficient number of the Forest Inventory and Analysis plots used by COLE to provide robust estimates. The Woodstock outputs did not specifically identify which cells were woodlands, so the BLM did not carry out this portion of the analysis as described in the Planning Criteria. Because wildfire was not included in the volume estimates for year 100, the BLM dropped that year from the analysis and added year 40, resulting in estimates for years 10, 20, 30, 40, and 50. **Appendix G** describes the carbon estimation method in further detail along with sources of uncertainty in the results.

The quantified analysis of changes in net carbon storage directly or indirectly incorporates the effects of land management actions, including timber harvest, prescribed burning, activity fuels treatments, and silvicultural treatments under the alternatives and the Proposed RMP through the vegetation modeling. Carbon affected by timber harvest has four potential fates:

- Removal from the site and processed into a wood product
- Removal from the site and burned as firewood or for energy production at a mill
- Retain on the site and burned in a fuels treatment
- Retain on the site and allowed to decay

The vegetation model accounted for the changes in net carbon storage from harvesting by reducing volume and affecting average stand age in the decade when timber harvest would occur.

The quantified analysis of changes in net carbon storage under the alternatives and the Proposed RMP does not incorporate the effects of hazardous fuels treatments[38] on net carbon storage, because it is not possible to estimate such effects on net carbon storage accurately and because the BLM assumes that the amount of hazardous fuels treatments would not vary among the alternatives and the Proposed RMP.

There is insufficient information on where and when the BLM would need to implement hazardous fuels treatments and how much biomass the treatments would remove. The BLM does not collect or store data on pre- and post-treatment biomass for the hazardous fuels treatments. Hazardous fuel treatments are highly variable in terms of acres treated and treatment methods. Hazardous fuel treatments are also highly variable in terms of treatment effects on carbon storage: not all fuels treatment methods remove the harvest residue and its carbon as a direct effect of the treatment. Material from treatments such as lop-and-scatter or mastication remains on site and decays naturally. Biomass removal, primarily for personal use firewood, currently accounts for only 4 percent of the acres treated under the hazardous fuels treatments, with an unknown amount of biomass affected. While biomass removal for commercial energy production may occur or increase in the future, currently low product value and high transportation costs means very few facilities have been built or planned within or near the planning area that would use forest residues as a fuel source, and none have been built that use forest residues as a primary fuel source. Since BLM cannot parameterize the stand conditions where the hazardous fuels treatments would occur, the BLM could not include hazardous fuels treatments in the vegetation model.

The primary effect of hazardous fuels treatments on net carbon storage comes from prescribed burning of piled vegetation, underburns, or broadcast burns. Factors influencing the amount of carbon removed by burning include pile size, pile shape, number of piles per acre, and amount of fuel both available and combusted through underburns or broadcast burns. With an estimated 173,300 acres of pile burning, underburns, and broadcast burning per decade, the additional reduction in net carbon storage from the hazardous fuels program would be less than 1teragram[39] of carbon (Tg C), or less than 1 percent, per decade. Because of the insufficient information about future hazardous fuels treatments, the high variability in the implementation of hazardous fuels treatments, and the high variability in the effects of hazardous fuels treatments on carbon storage, this estimation of the effects of hazardous fuels treatments under the alternatives and the Proposed RMP at this scale of analysis is of very low accuracy. The BLM includes this estimation here to give context to the magnitude of the potential effect of hazardous fuels treatments on net carbon storage.

It is possible that hazardous fuels treatments (and other land management actions) could indirectly reduce the loss of new carbon storage resulting from wildfire by reducing the severity and extent of future wildfires. However, it is not possible to quantify any change in future wildfire effects resulting from hazardous fuels treatments (see the Fire and Fuels section in this chapter).

[38] Hazardous fuel treatments are non-commercial treatments that are designed to reduce existing, natural fuel accumulations. In contrast, activity fuel treatments are designed to reduce fuel accumulations created by management actions such as timber harvest (see the Fire and Fuels section in this chapter). The BLM assumed in this analysis that implementation of hazardous fuels treatments would not vary by alternative and the Proposed RMP. However, activity fuel treatments would vary by alternative and the Proposed RMP, because the BLM would implement activity fuel treatments in response to fuels created by differing management actions.

[39] Scientific literature on carbon storage at this scale of analysis reports carbon amounts in metric tons, which are equal to approximately 2,205 pounds. One million metric tons equals one teragram.

In addition to comparing the alternatives and the Proposed RMP, the BLM also considered two reference analyses as a means of providing additional context for the alternatives and the Proposed RMP: the No Timber Harvest Reference Analysis without wildfire (providing an estimate of potential carbon storage resulting from the vegetation growth) and the No Timber Harvest reference analysis with wildfire. Comparing these two reference analyses allowed the BLM to estimate the effect of this natural disturbance alone and then in conjunction with harvesting in the alternatives and the Proposed RMP.

The quantified analysis of changes in net carbon storage under the alternatives and the Proposed RMP does not incorporate the potential effects on carbon storage from changing climate conditions. The vegetation modeling did not incorporate projections of climate change into the simulation of the growth of stands through time (see the Vegetation Modeling section in this chapter). Climate change would alter the absolute estimates of net carbon storage over time, but would not alter the relative outcomes under the alternatives and the Proposed RMP. Based on recent research, climate change would likely result in smaller increases in future carbon storage in the decision area than estimated in this analysis, though differences may not be apparent within the time frame of this analysis. Using a different analysis method than the carbon analysis in this Proposed RMP/EIS that accounted for changing climate, Diaz *et al.* (2015) also found that net carbon storage in trees would increase on BLM-administered lands within the planning area until mid-century and then level off under lower emissions scenarios and decline under other emissions scenario. Creutzburg *et al.* (2016) found that climate change would slow expected carbon accumulation rates in the northern Coast Range by about 8 percent relative to a static climate, largely between mid-century and the end of the century, but that total carbon would continue to increase. Rogers *et al.* (2015), using three different climate models, found that in western Oregon and Washington, carbon storage would increase slightly under two of the models by the end of the century but decline substantially under the third model.

Future carbon storage on BLM-administered lands could differ from these estimates if the use of biomass for energy increases substantially. Using harvest-generated residues for bioenergy is a common proposition to reduce emissions from burning fossil fuels and both greenhouse gas and particulate emissions associated with prescribed burning to remove such residues. Although such changes in biomass utilization are possible, they are not reasonably foreseeable at this time (see the Sustainable Energy section in this chapter). A recent study in the Panther Creek watershed in northwestern Oregon indicates that if both private forests and BLM-administered lands were to ‘capture’ such residues for bioenergy production, net carbon storage would decline by only 2–3 percent relative to conventional harvest methods (Creutzburg *et al.* 2016). Rotation length and the age at which no harvesting would occur on BLM-administered lands had the main effect on carbon storage in the watershed, which includes a mix of BLM-administered and private lands. This same study also found that longer rotations and less intensive management on Federal and non-corporate private lands could counterbalance shorter rotations and more intensive management on private lands (Creutzburg *et al.* 2016).

There are multiple sources of uncertainty in estimating the amount of carbon stored on the BLM-administered lands within the planning area, which are discussed in more detail in **Appendix G**. Although it is not possible to quantify all of the sources of error, the potential error in the estimate for any one alternative and the Proposed RMP likely exceeds the amount of variance among the alternatives and the Proposed RMP. The U.S. Forest Service estimated standard errors ranging from 20 percent to slightly over 50 percent, averaging around 33 percent, for their lands in western Oregon (USDA FS 2015). The BLM standard errors are likely similar, albeit on the higher end of this range, given the estimation methods used.

Affected Environment

The BLM-administered lands within the planning area currently store an estimated 360 Tg C (**Table 3-13**). In the 2008 FEIS, BLM estimated current carbon storage at 427 Tg, using a similar but more simplified approach that relied primarily on regional averages (USDI BLM 2008, pp. Appendices – 28-29). The type of data available in 2008 for estimating carbon storage did not allow the more detailed approach used in this analysis.

Table 3-13. Estimated current total carbon stored in vegetation and soil and carbon density

District/ Field Office	Acres	Total Carbon (Tg C)	Carbon Density (Mg C/Acre)
Coos Bay	313,945	59	190
Eugene	300,736	60	198
Klamath Falls	210,386	9	41
Medford	782,524	93	119
Roseburg	408,680	63	155
Salem	385,806	76	196
Totals	**2,402,076**	**360**	**-**

The Medford District currently stores the most carbon, with an estimated 93 Tg C, largely due to the size of the district. The Klamath Falls Field Office stores the least, approximately 9 Tg C, largely due to the high proportion of non-forest plant communities within the Field Office boundaries and the small size of the Field Office. Approximately 6 Tg C is currently stored in products made from wood harvested from BLM-administered lands that are either still in use or are located in sanitary landfills where decay rates are minimal (Earles *et al.* 2012). In the 2008 FEIS, the BLM estimated carbon storage in landfills and wood products was 11 Tg C using an approach based on the assumed proportion of pulpwood to saw logs and estimates of the cumulative emissions of carbon over time by each type of product (USDI BLM 2008, pp. Appendices – 30). In this analysis, the BLM estimated carbon storage in landfills and wood products using a decay function derived from Earles *et al.* (2012) that consolidated the same type of information used in 2008 with estimates from the Oregon Department of Forestry on the annual board foot volumes harvested from BLM-administered lands within the planning area from 1965 through 2012. The combination of carbon stored on the districts and in wood products brings the total estimated carbon storage currently associated with BLM–administered lands in the planning area to 366 Tg C.

Carbon density, the amount of carbon per acre, provides a comparable measure between the districts that reflects carbon storage capability and general productivity. The Coos Bay, Eugene, and Salem Districts are moderate in size but have a high carbon density (**Table 3-13**). The Medford District has the largest acreage of BLM-administered lands of the administrative units in the decision area, and has the largest amount of total carbon storage, but has the second lowest estimated carbon density. The Klamath Falls Field Office has the smallest acreage of BLM-administered lands of the administrative units in the decision area and has the lowest carbon density.

Environmental Consequences

Timber harvest volume removed is the primary driver of differences across the alternatives and the Proposed RMP in net carbon storage on BLM-administered lands in the planning area, although a portion of the material harvested remains stored for up to 150 years in the form of wood products in use or in sanitary landfills (Earles *et al.* 2012). Comparing the No Timber Harvest reference analysis without fire to the No Timber Harvest Reference Analysis with fire indicates that wildfire reduces estimated net carbon storage by 0.4–0.7 percent across the planning area through 2063, varying by decade. For the Coos Bay, Eugene, and Salem Districts, and the Klamath Falls Field Office, the estimated reduction would be generally less than 0.3 percent of the net carbon stored on those Districts. On the Roseburg District, the reduction would be highly variable, ranging from as little as 0.12 percent to as high as nearly 3 percent.

The expected reduction on the Medford District would be less variable, ranging from 1 to 2 percent, given that approximately 82.5 percent of the acres burned are predicted to occur on that district.

All alternatives and the Proposed RMP, including the No Action alternative, would increase net carbon storage over time relative to the current condition (**Figure 3-13** and **Figure 3-14**). Differences among the alternatives and the Proposed RMP, and in comparison to the No Timber Harvest Reference Analysis with fire, would be minor until around 2033, and afterwards would become increasing apparent. Although Alternative D has the second largest Harvest Land Base of the alternatives and the Proposed RMP, the volume removed per acre would be low due to the overall approach to timber management (see the Forest Management section in this chapter). Alternative D would store the most net carbon, followed, in order, by Alternative A, the Proposed RMP, Alternative B, No Action, and Alternative C. The differences in net storage among the Proposed RMP, Alternative A, and Alternative B would be quite small. Carbon stored in wood products would range from an estimated 5 to 10 Tg, depending on alternative and the Proposed RMP and decade.

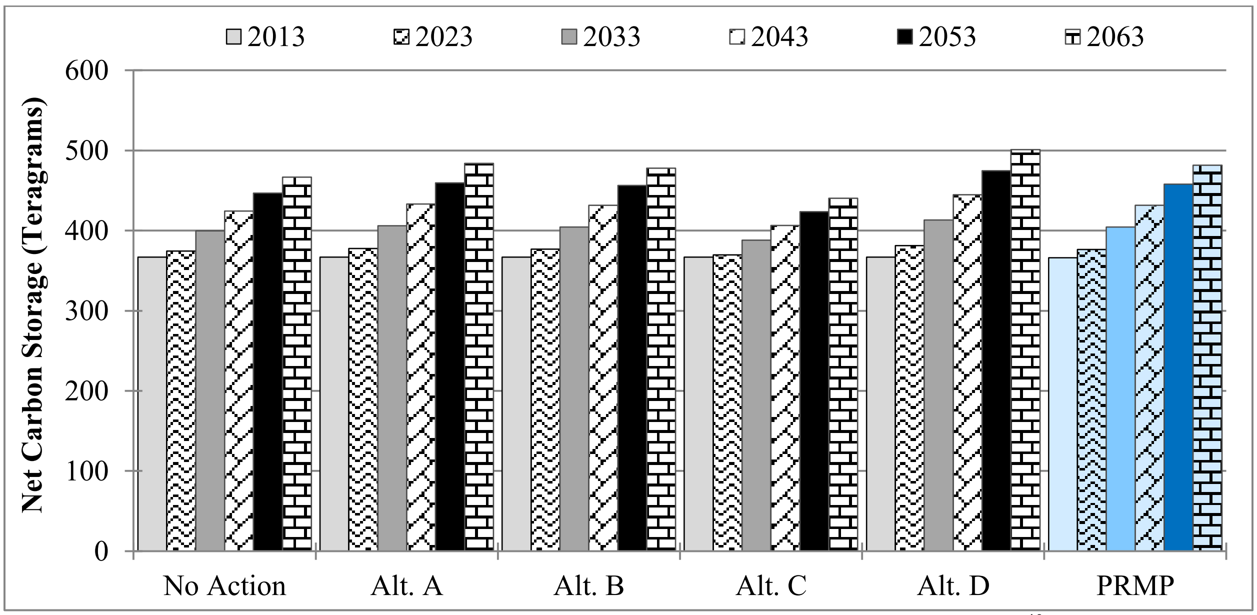

Figure 3-13. Estimated carbon storage over time by alternative and the Proposed RMP[40]

[40] The 2013 value for the Proposed RMP is slightly less than the alternatives, because the BLM has updated current vegetation baseline information to incorporate the effects of the 2013 and 2014 fire seasons (see the Analytical Methodologies and Assumptions section of this chapter).

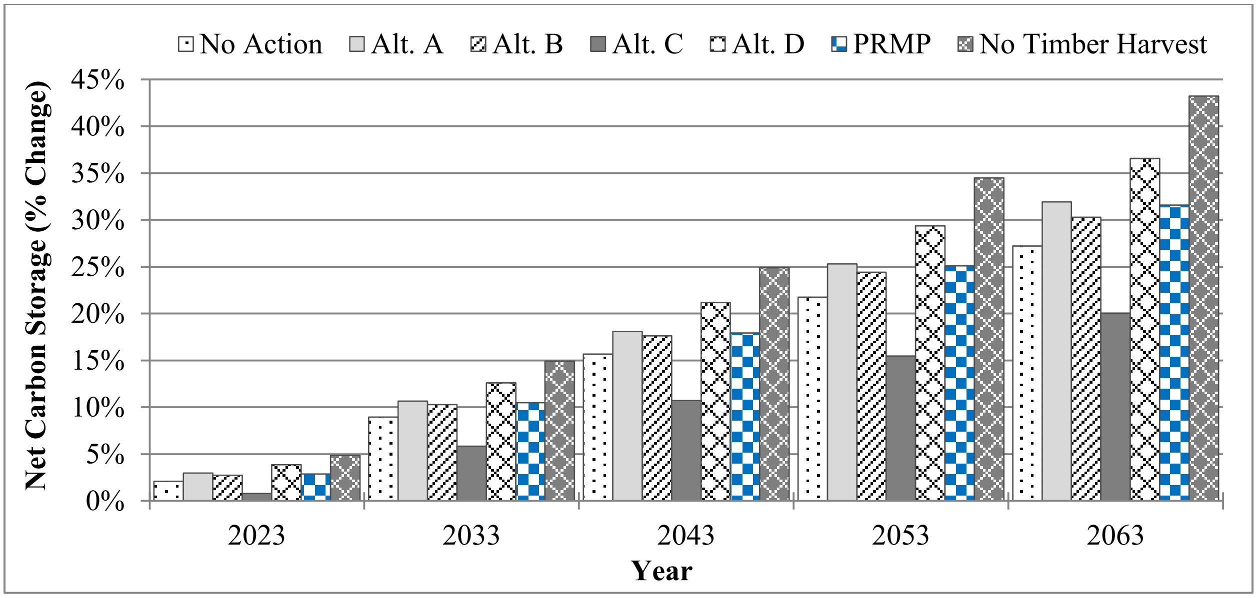

Figure 3-14. Change in carbon storage relative to the estimated total storage as of 2013

All alternatives and the Proposed RMP would increase net carbon storage, but not as much as under the No Timber Harvest reference analysis with wildfire (**Figure 3-15**). The difference in the increase in net carbon storage occurs as harvesting removes carbon and shifts stand characteristics, such as mean diameters and heights, in more of the landscape to smaller trees and younger age classes that store less carbon. Since Alternative C would harvest the most volume over time and would have the highest percentage of the landscape in younger age classes dominated by smaller trees, relative to the No Timber Harvest reference analysis, it would have the lowest increases in net carbon storage. After 2033, the Proposed RMP would store slightly less carbon than Alternative A, and slightly more carbon than Alternative B.

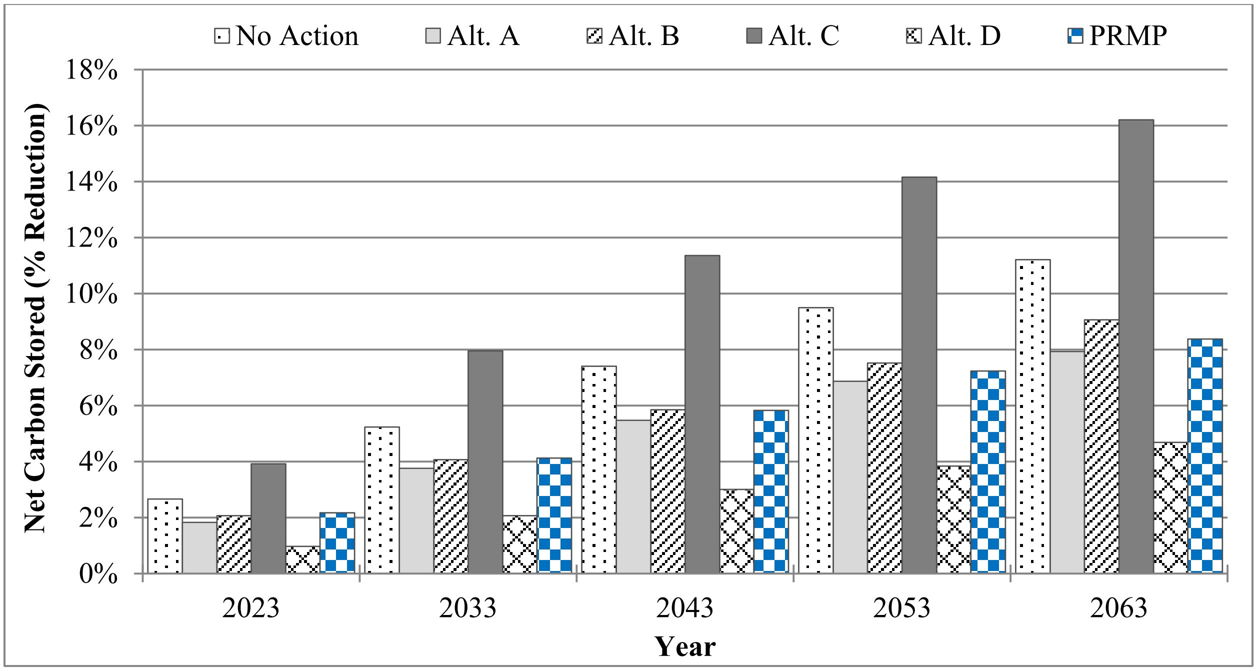

Figure 3-15. Percent reduction in aboveground carbon storage from timber harvest relative to projected carbon storage in the No Timber Harvest reference analysis with wildfire

Effect of Net Carbon Storage on BLM-administered Lands in the Context of Other Lands

Placing carbon storage on BLM-administered lands in context of other lands in the planning area is difficult due to the nature of the data available, which is variable in extent of geographic coverage, in assessment dates, and in the carbon pools assessed. The most recent published statewide assessment covered live and dead trees and downed wood measured between 2001 and 2005, but does not include all carbon pools (Donnegan *et al*. 2008). In that assessment, all the forests in Oregon, including juniper woodlands, store an estimated 1,215 Tg C in live and dead trees and downed logs and large branches. That assessment concluded that U.S. Forest Service lands, privately owned lands, and the BLM-administered lands store 56.7, 23.3, and 11.8 percent of the statewide total, respectively. The estimated statewide total for all BLM-administered lands (which includes BLM-administered lands outside of the decision area) of 144 Tg C as of 2005 is considerably less than the BLM estimated in either the 2008 FEIS analysis or in this analysis for western Oregon. Other Federal lands, State and local government lands, Tribal lands, and other private lands stored the remaining 8.4 percent, with slightly over half of that amount on State forests.

The U.S. Forest Service has also estimated the amount of carbon stored in all pools (live and dead trees, downed wood, litter and duff, and the top meter of soil) for all U.S. Forest Service lands in 2013, providing a basis of comparison with BLM-administered lands in the decision area. The BLM obtained the data for the Fremont, Mt. Hood, Rogue River-Siskiyou, Siuslaw, Umpqua, and Willamette National Forests to compare with the BLM estimates above. The BLM-administered lands (which constitute 34.8 percent of the acreage of U.S. Forest Service lands) stored approximately 39.4 percent of the amount of carbon stored on U.S. Forest Service lands;[41] that is, carbon is stored on BLM-administered lands at 113.3 percent of the density as on U.S. Forest Service lands (**Table 3-14**).

[41] This comparison does not account for the effects of wildland fires in 2013 and 2014, which affected both BLM-administered lands and U.S. Forest Service lands.

Table 3-14. Estimated carbon storage and carbon density for the major land ownerships in western Oregon

Land Owner/ Manager	Assessment Period	Total Carbon* (Tg C)	Acres	Carbon Density (Mg C/Acre)
BLM	2013	361	2,402,076	150.4
U.S. Forest Service	2013	916	6,900,020	132.8
State of Oregon	2001–2010	96	789,610	122.0
Private Landowners	2001–2010	559	6,614,392	34.2

* Does not include carbon stored in wood products still in use or in landfills

Based on data from 2001 through 2010, forests managed by the state of Oregon in western Oregon have a slightly lower carbon density than the U.S. Forest Service lands (Gray 2015, personal communication; **Table 3-14**). This lower carbon density may be due to the amount of area in younger forests, such as the Tillamook State Forest, even though most of the State forestlands are located in the highly productive Coast Range or at similar elevations as the BLM-administered lands in the Cascade Range. Although private forestlands in western Oregon store a large amount of carbon and encompass an area similar in size as U.S. Forest Service lands, they have the lowest carbon density (Gray 2015, personal communication, **Table 3-14**), likely due to the predominance of intensively managed forests, which the owners typically manage on a 40- to 60-year rotation.

Carbon storage increased on the western Oregon U.S. Forest Service lands by approximately 1.73 Tg/yr between 1990 and 2013, despite the decreases on the Siskiyou National Forest and the apparent stabilization on the Rogue River National Forest (USDA FS 2015). Gonzalez *et al.* (2015) reported that forest ecosystems in California lost carbon between 2001 and 2010, which they attributed principally to recent large wildfires in northern California and the Sierra Nevada Mountains. Southwest Oregon may be experiencing a similar effect given the high similarity in forest types with northern California and recent increases in area burned. The BLM does not know whether the BLM-administered lands in southwest Oregon (primarily Medford and Roseburg Districts) are experiencing the same loss or stagnation in carbon storage given the lack of long-term annual carbon data.

Carbon storage on BLM-administered lands in the decision area likely increased by a similar amount given the similarity in management between the BLM and the U.S. Forest Service over that period. The BLM estimated net carbon storage would increase by a low of 1.5 Tg/yr under Alternative C to a high of 2.7 Tg/yr under Alternative D. Under the Proposed RMP, carbon sequestration would average 2.3 Tg/yr over the next 50 years. However, these estimates do not account for potential sources of mortality other than fire and potential increases in wildfire occurrence, size, or severity that might reduce that sequestration rate. The expected increase in net carbon storage as well as other forest management actions (see the Forest Management section in this chapter) under all alternatives and the Proposed RMP supports the Oregon interim strategy for reducing greenhouse gas emissions, although to what degree is not known since the State has not established specific carbon storage goals (OGWC 2010, 2013).

Issue 2

What would be the BLM's expected contribution to greenhouse gas emissions from vegetation management activities such as timber management and prescribed burning?

Summary of Analytical Methods

In this issue, the BLM estimated the gross greenhouse gas emissions from timber harvest, prescribed burning, wildfires and livestock grazing. These estimates are the direct emissions for all greenhouse gases emitted through natural processes (carbon dioxide, methane, and nitrous oxide). The carbon analysis under Issue 1 accounts for the carbon losses from fire and timber harvest by evaluating changes in net carbon storage. This analysis includes all greenhouse gases, including those that lack carbon (nitrous oxide), and all relevant sources of emissions, including those that do not directly affect net carbon storage. Because methane and nitrous oxide have higher global warming potential than carbon dioxide, the BLM followed global and national standards by reporting greenhouse gas emissions as carbon dioxide equivalents (CO_2e). One methane molecule effectively equals 25 carbon dioxide molecules and one nitrous oxide molecule effectively equals 298 carbon dioxide molecules.

Greenhouse gas emissions from BLM management activities that are most likely to be substantial and to vary among alternatives and the Proposed RMP are timber harvesting, grazing, and prescribed burning. A wide variety of BLM activities produce greenhouse gases, but the absence of reliable data limits the BLM's ability to estimate emissions. For example, BLM-authorized mining operations are a source of greenhouse gases, but there is no data on which to base estimates of emissions from this sector, particularly since mining operations within the decision area currently involve salable and locatable minerals only (USDI BLM 2013, pp. 57–58). The BLM has no information on the type of equipment used for mining or for how long (see also the Minerals section in this chapter). The BLM could not locate any general information on greenhouse emissions from mining other than for coal; coal mining does not occur within the planning area.

The BLM estimated greenhouse gas emissions for each alternative and the Proposed RMP, expressed in the form of carbon dioxide equivalent (CO_2e), using projected timber harvest, permitted levels of grazing, and prescribed burning. The Planning Criteria provides more detailed information on analytical assumptions, methods and techniques, and geographic and temporal scales, which is incorporated here by reference (USDI BLM 2014, p. 38). The BLM changed the method for this analysis from what was described in the Planning Criteria by providing a greenhouse gas emission for year 40 and by not estimating emissions past year 50, since that was the last year for which the BLM modeled wildfire.

The BLM estimated emissions from timber harvest by converting the estimates of board feet harvested to cubic feet and applying the emissions factor listed in the Planning Criteria (USDI BLM 2014, p. 38). The BLM estimated methane emissions from public lands grazing using the emission factor described by the Intergovernmental Panel on Climate Change (Eggleston *et al*. 2006). Instead of the emission factor listed in the Planning Criteria for prescribed fires, the BLM used estimated emissions from Consume 4.2 for carbon dioxide and methane and the emission factor provided by the Environmental Protection Agency for burning wood and wood products as a stationary source for nitrous oxide (EPA 2014a, Table 1) as the BLM believes these emission estimation methods are more accurate than the single emission factor initially proposed in the Planning Criteria. To provide context for the emissions from harvesting and prescribed burning, the BLM also estimated greenhouse gas emissions from wildfires. The BLM used a combination of wildfire records, fuelbeds from the Fuels Characteristic Class System (FCCS) version 3.0, and emissions estimates from Consume 4.2 to estimate emissions from wildfires. **Appendix G** details the estimation methods and associated uncertainties.

This analysis may overestimate greenhouse gas emissions from both prescribed fire and wildfire. At least some of the carbon produced by wildland fires is deposited as pyrogenic organic matter, also known as charcoal, biochar, and black carbon, instead of being emitted into the atmosphere (Lehmann *et al*. 2006, Sohi *et al*. 2010, Santín *et al.* 2015). The amount of biochar produced depends on fire intensity (Nocentini *et al*. 2010, Sohi *et al*. 2010, Santín *et al*. 2012) and lignin content (Lehmann *et al*. 2006, Makoto *et al*.

2011). Biochar produced by wildland fire can persist in soils for several hundred to several thousand years (e.g., Spokas 2010, Sohi *et al*. 2010, Criscuoli *et al*. 2014, Santín *et al*. 2015, and Wang *et al*. in press), providing storage instead of emission. Factors governing the durability of biochar in the soil include soil texture (Pingree *et al*. 2012 and references therein), particle size (Nocentini *et al*. 2010), the oxygen to carbon ratio in the particles (Spokas 2010), and fire frequency (Nocentini *et al*. 2010, Pingree *et al*. 2012). Estimates of the amount of biochar produced vary widely, however, ranging from 1 to 28 percent of the above ground biomass (Lehmann *et al*. 2006, Sohi *et al*. 2010, Pingree *et al*. 2012, Santín *et al*. 2015), making any attempt to estimate this potential reduction in greenhouse gas emissions highly uncertain.

Background

Globally, atmospheric carbon dioxide (CO_2) concentrations have increased from an estimated 277 ppm (parts per million) before 1750 to 395.31 ± 0.1 ppm in 2013, the highest level in the last 800,000 years according to the Global Carbon Project (2015). Preliminary estimates indicate global atmospheric CO_2 concentrations reached 397.15 ppm in 2014. According to CO_2Earth.org (2015), monthly atmospheric CO_2 concentrations surpassed the 400 ppm benchmark during April through June of 2014 and February through July of 2015 at the Mauna Loa Observatory. Carbon dioxide is the primary greenhouse gas, comprising over 80 percent of total emissions globally, as well as in both the U.S. and Oregon. Fossil fuel combustion is the primary source of CO_2 (McConnaha *et al*. 2013, Le Quéré *et al*. 2014, 2015; EPA 2014b, 2015). United States emissions of greenhouse gasses (6,673 Tg CO_2e) were 14 percent of global emissions (~ 47,664 Tg CO_2e) in 2013 (Le Quéré *et al*. 2015; EPA 2015). In 2010, the latest year in which data are available, Oregon's emissions were about 1 percent of the U.S. emissions (McConnaha *et al*. 2013, EPA 2014b). Globally, ocean and land greenhouse gas sinks removed about 50 percent of that emitted in 2013 (Le Quéré *et al*. 2015). Land sinks in the U.S. effectively reduced total greenhouse gas emissions by 13.2 percent nationally in 2013, with forests and wood products accounting for about 11.5 percent (EPA 2015). The forests of western Oregon sequester more carbon per acre than the national average (Joyce *et al*. 2014, Figure 7.5).

Several scientific studies have concluded that greenhouse gas emissions from human activities are driving relatively rapid climate change (IPCC 2013 and references therein). Under the current state of the science, however, the BLM cannot identify the impacts of greenhouse gas emissions from any one project or program, or from its activities in western Oregon on global, national, or even local climate. In 2004, the state of Oregon released its statewide strategy for greenhouse gas reductions. Oregon's goal is to reduce statewide greenhouse gas emissions to at least 75 percent below 1990 levels by 2050, or to approximately 15 Tg CO_2e (ODOE 2004). To achieve this goal the State strategy calls for increased energy conservation, increased energy efficiency among natural gas and oil users, increased efficiency in transit and alternatives to driving cars and trucks, primarily in urban areas along the I-5 corridor, increased use of products that use less energy to produce and are designed for reuse or easy recycling, replacing fossil fuels with alternative energy sources, and increasing carbon capture and storage in forests and farms (ODOE 2014). Of these elements, BLM-administered lands would support this strategy through increased carbon capture and storage in forests.

Affected Environment

Total estimated greenhouse gas emissions from timber harvest, grazing, and prescribed fire on BLM-administered lands within the planning area averaged 122,398 Mg CO_2e/yr over the past 19 years (1995–2013) (**Figure 3-16**), or about 0.2 percent of Oregon's in-boundary[42] 2010 emissions (McConnaha *et al.* 2013). Prescribed fires emitted about 90 percent of the BLM management-related greenhouse gases. In contrast, average emissions from wildfires that originated on BLM-administered lands were

[42] In-boundary emissions are those that occur within Oregon's borders and emissions associated with electricity use within Oregon.

approximately 69,636 Mg CO_2e/yr or about 36 percent of all greenhouse gas emissions originating on BLM-administered lands within the planning area over the past 19 years (**Figure 3-16**). Prescribed fires emitted more greenhouse gases, on average, than wildfires over this time period. Emissions for any one year varied widely, largely depending on the amount of prescribed fire and wildfire, although emissions from prescribed fires varied much less than those from wildfires.

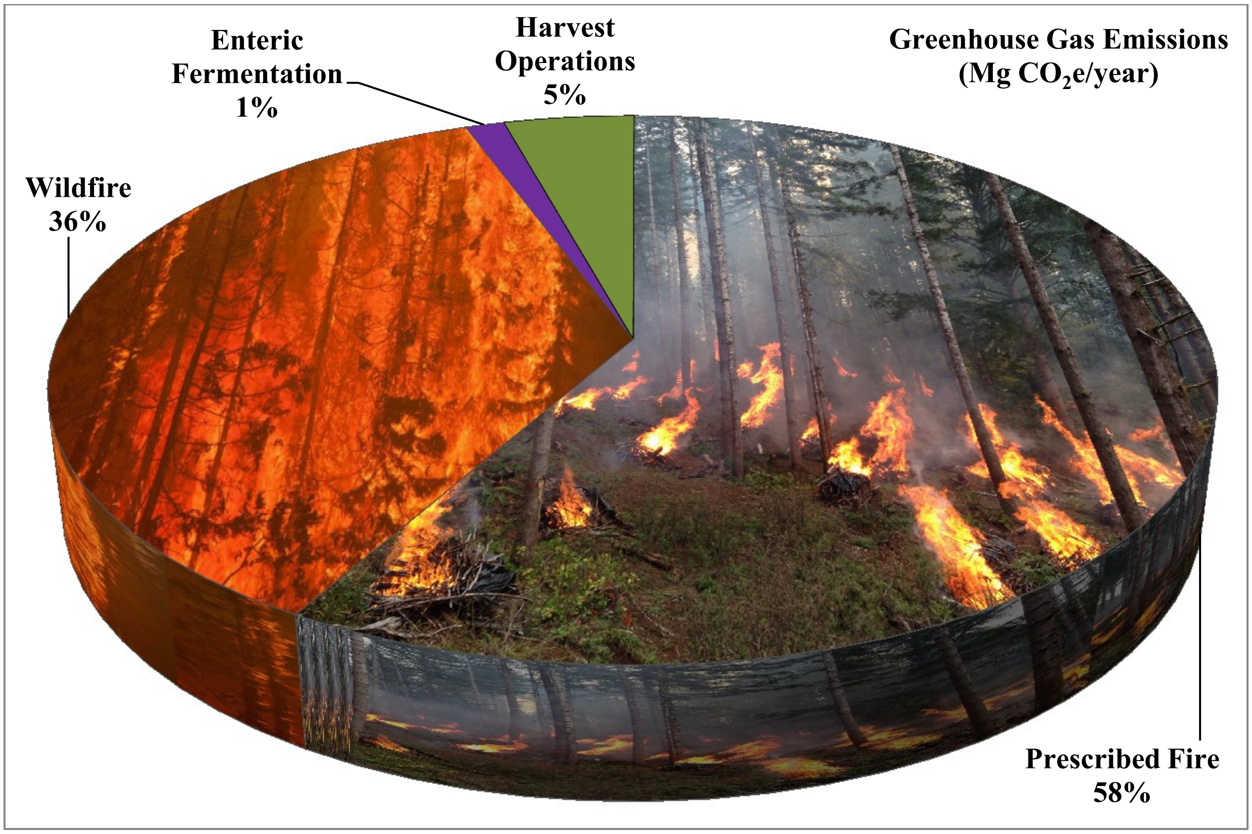

Figure 3-16. Proportion of estimated greenhouse gas emissions from livestock grazing (enteric fermentation), timber harvest operations, prescribed fires, and wildfires on BLM-administered lands within the planning area

The estimate of current greenhouse gas emissions for BLM-administered lands within the planning area represents the actual level of activity. This is in contrast to the analysis of the No Action alternative in the following section, which projects future implementation of 1995 RMPs as written. Actual harvest levels and grazing have been below what the 1995 RMPs anticipated (USDI BLM 2013). Therefore, prescribed burning of activity fuels created by harvesting activities is generally less than what was anticipated in 1995, but prescribed burning of so-called natural fuels, or hazardous fuels, under the National Fire Plan (USDA FS and USDI BLM 2000) has partially compensated for the reduction in activity fuels burning. The National Fire Plan increased funding for hazardous fuels reduction beginning in 2001.

The available data do not indicate how much of the prescribed burning was activity fuel reduction and how much was hazardous fuels reduction. The BLM explicitly designs the hazardous fuels reduction program to reduce potential fire behavior and effects and, hence, greenhouse gas emissions from wildfires. While the BLM does not design silvicultural treatments to reduce hazardous fuels, many treatments serve to do that as a secondary benefit of enhancing tree growth on the remaining trees (see also the Fire and Fuels section for additional analysis and references). Many studies also demonstrate that reducing the fuels created by any forest vegetation treatment, regardless of the primary purpose of the treatment, is essential to reducing potential wildfire behavior and effects and resulting greenhouse gas emissions (e.g., Pritchard *et al.* 2010, Lyons-Tinsley and Peterson 2012, Safford *et al.* 2012, and Shive *et al.* 2013).

The BLM is a relatively small emitter of greenhouse gases from harvest operations and prescribed fire within the planning area (**Figure 3-17**, the Other Federal category is largely BLM). Management on private forests and on U.S. Forest Service lands each result in greater emissions. In large part, these differences reflect the differences in land base and, in the case of private forests, management intensity. Prescribed fire emissions in private forests are largely due to clean up of harvest-generated residue (activity fuels), whereas a portion of the prescribed fire emissions from U.S. Forest Service lands and BLM-administered lands arises from the hazardous fuels reduction program in both agencies under the National Fire Plan.

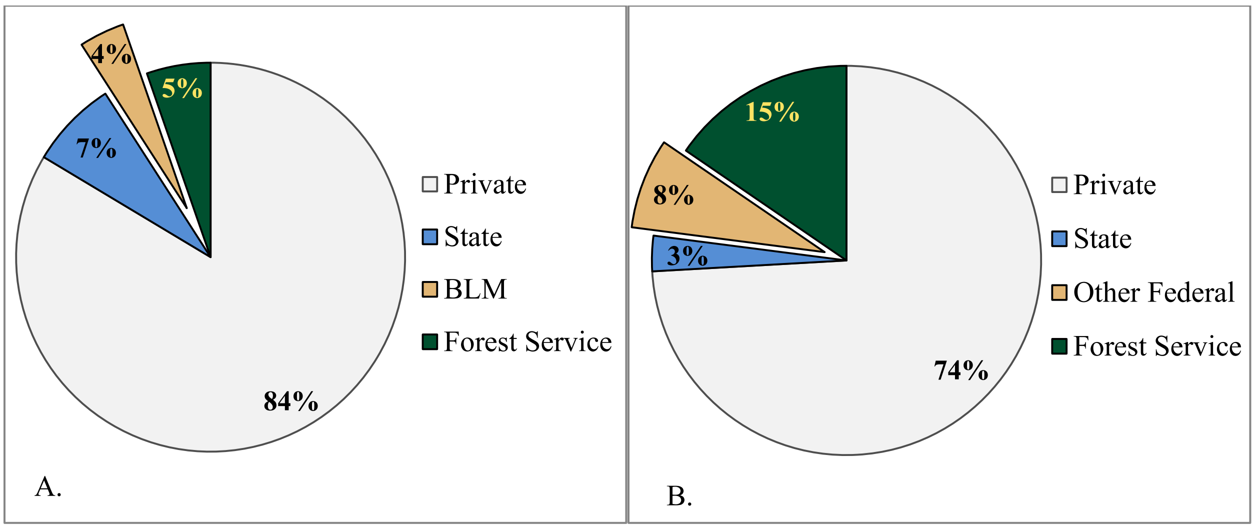

Figure 3-17. Proportion of estimated greenhouse gas emissions from (a) timber harvest and (b) prescribed burning by different entities

Trends in emissions are more difficult to ascertain. Emissions from grazing on BLM-administered lands within the planning area have very slightly declined since 1995, as more allotments became vacant and the amount of active use declined. No trend is evident in wildfire emissions due to very high interannual variability in the acres burned on BLM-administered lands over the period of record (1980–2013).

Although interannual variability in emissions from harvest operations and prescribed burning is also high, some trends are apparent. Harvesting on private forests reflects current economic conditions, particularly in the housing market. During the recent housing boom, harvesting and the resulting greenhouse gas emissions from private land harvesting increased from the late 1990s until 2007. Between 2007 and 2009, emissions declined sharply, reflecting the economic downturn, which had a substantial impact on housing demand and lumber. This same effect on greenhouse gas emissions was also apparent nationally (EPA 2014b). Since 2009, harvesting levels and associated emissions have recovered to pre-recession levels. In contrast, harvesting levels and resulting emissions have been slowly increasing on both BLM-administered and U.S. Forest Service lands since 2001, with a slightly higher trend on the U.S. Forest Service lands.

The trends in emissions from prescribed burning do not track the trends in emissions from harvesting operations. On private forests, emissions from prescribed burning have fallen since about 2006, even when harvest levels have risen. Whether the continued fall represents a lag between time of harvest and time of site preparation, a reduction in activity fuels due to higher utilization, or a shift in how the land managers handled activity fuels is unknown. Fluctuations in emissions from prescribed burning on BLM-administered lands and the U.S. Forest Service lands within the planning area may reflect a combination of higher utilization and fluctuations in the hazardous fuels program. Since 2009, prescribed fire emissions from U.S. Forest Service lands have risen slowly, while emissions have fallen slowly on BLM-administered lands.

Environmental Consequences

As with particulate emissions (see the Air Quality section of this chapter), the amount of activity fuels prescribed burning is the primary factor driving the differences between alternatives and the Proposed RMP and over time. Greenhouse gas emissions from BLM activities would increase substantially relative to the estimate of current actual emissions under all alternatives and the Proposed RMP, with the exception of Alternative D (**Figure 3-18** and **Figure 3-19**). This increase would be largely due to the amount of prescribed burning that would occur in conjunction with harvesting. Alternative C would result in the largest increases. However, even the highest projected emissions under Alternative C would remain less than 1 percent of Oregon's 2010 in-boundary greenhouse gas emissions and approximately 0.0008 percent of total U.S. greenhouse gas emissions in 2012 (EPA 2014b, Figure ES-1). Greenhouse gas emissions under Alternative B would be the second highest of all alternatives and the Proposed RMP. The Proposed RMP and Alternative A would result in similar emissions, lower than Alternative B and the No Action alternative. Alternative D would result in the lowest emissions of all alternatives.

The BLM has considered measures that would reduce or avoid increases in greenhouse gas emissions above current levels. The current implementation of the timber management program is not consistent with the 1995 RMPs as written (see the Purpose and Need for Action section in Chapter 1; current implementation has been predominately thinning, and the current practices are not sustainable at the declared timber harvest levels (see the Alternatives Considered but not Analyzed in Detail section of Chapter 2). The current level of greenhouse gas emissions is substantially lower than the emissions that this analysis shows would result from implementation of the No Action alternative. The level of sustained-yield timber production and associated prescribed burning generally would reflect the level of greenhouse gas emissions. Any alternative that would provide a sustained yield of timber and restore fire-adapted ecosystems would necessarily result in increases in greenhouse gas emissions above current levels. The alternatives and the Proposed RMP would result in varying amounts of increase in greenhouse gas emissions above current levels. However, it would not be possible to avoid increases in greenhouse gas emissions above current levels and meet the purposes of the action.

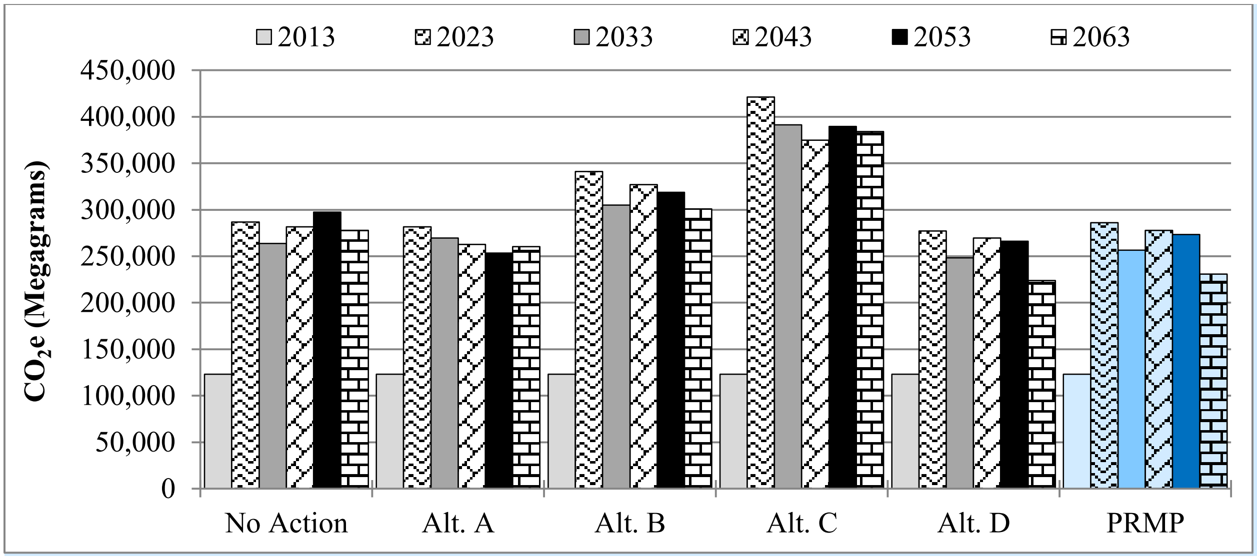

Figure 3-18. Estimated average annual greenhouse gas emissions from the combination of timber harvest, grazing, and prescribed fire

Note: Variation in activity fuels prescribed fire levels causes most of the fluctuation in expected emissions between decades.

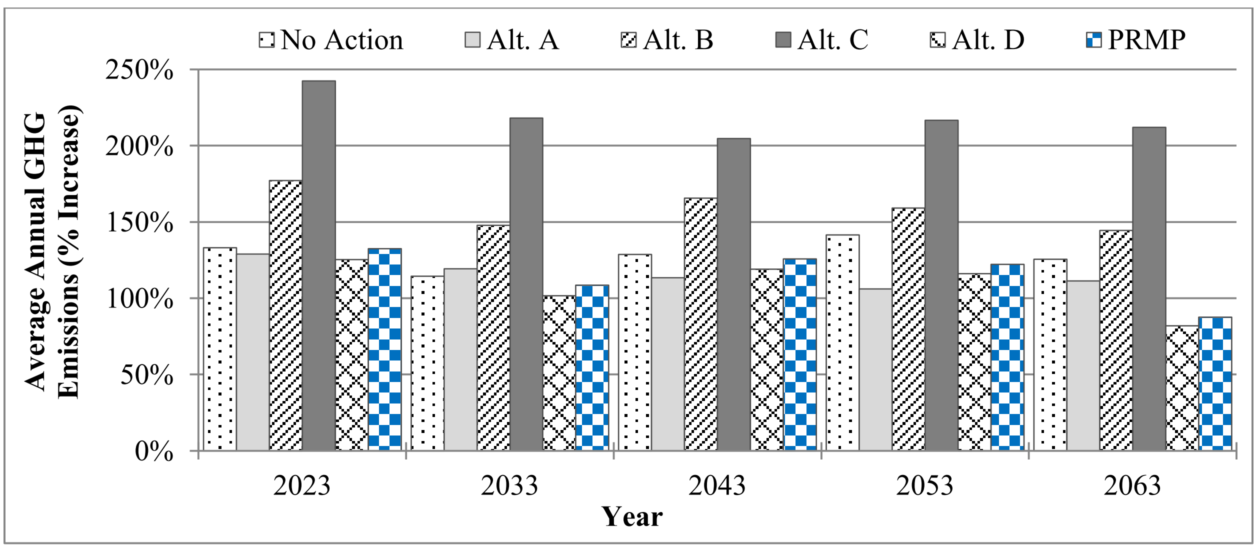

Figure 3-19. Projected increases in average annual greenhouse gas emissions from timber harvest, grazing, and prescribed burning relative to average annual emissions as of 2013

Effect of Greenhouse Gas Emissions from BLM-administered Lands in the Context of Other Sources

Placing BLM's greenhouse gas emissions in a statewide or national context is difficult for the same reasons as discussed above for carbon storage. In addition, greenhouse gas emissions are rarely estimated for the forestry subsector alone. The EPA groups emissions from forestry operations into the agricultural sector. In 2013, national emissions from the agricultural sector were 586.8 Tg CO_2e, or 8.8 percent of total U.S. emissions. Land use and forestry emissions accounted for 1.9 percent of agricultural emissions, or 10.9 Tg CO_2e (EPA 2015). Data for the state of Oregon does not include an estimate of emissions from land use and forestry.

The 2013 estimate for BLM's greenhouse gas emissions are 0.2 percent of the U.S. 2013 estimate for the agriculture sector. The BLM greenhouse gas emissions through 2063 would range from 0.3 to 0.7 percent of the U.S. 2013 estimate for the agricultural sector. Greenhouse gas emissions for each alternative and the Proposed RMP would fluctuate over the assessment period, depending on the extent of timber harvest and subsequent prescribed burning. Greenhouse gas emissions from timber harvest operations would be a higher proportion of BLM total emissions than they are in the national emissions, ranging from as low as 4.2–5.4 percent under Alternative D to as high as 8.6–9.4 percent under Alternative C. Under the Proposed RMP, harvest emissions would account for between 5.2–6.4 percent of BLM's expected total greenhouse gas emissions. The BLM emissions differ from the national emissions for the agricultural sector in that livestock and crop cultivation produced 90 percent of the national emissions whereas prescribed burning is expected to produce 90–96 percent of the emissions from BLM, depending on the alternative and decade.

The BLM also compared how the relative proportions of greenhouse gas emissions would change for harvesting and prescribed fire assuming no change in the emissions from private forest owners, the State of Oregon, and other Federal agencies, using average annual estimates over the entire analysis period (50 years). The BLM's proportion of annual harvesting-related greenhouse gas emissions would increase from about 4 percent of the western Oregon estimate to a low of 5 percent per year under Alternative D and a high of 14 percent per year under Alternative C. The Proposed RMP annual harvesting greenhouse gas emissions would approximately double to an estimated 8 percent of western Oregon harvesting emissions, or 0.02 Tg CO_2e per year on average. The BLM's proportion of greenhouse gas emissions from prescribed burning would increase from approximately 8 percent per year of the western Oregon total to a low of 15 percent per year under Alternative D and a high of 20 percent per year under Alternative C. The Proposed RMP prescribed fire greenhouse gas emissions would increase to 17 percent of the western Oregon prescribed fire emissions, or 0.28 Tg CO_2e per year, on average.

Issue 3

How would climate change interact with BLM management actions to alter the potential outcomes for key natural resources?

Summary of Analytical Methods

In this analysis, the BLM considered both how climate change would introduce uncertainty into outcomes described in other sections of this chapter and how the alternatives and the Proposed RMP might allow the BLM to undertake actions to adapt to climate change during plan implementation. The BLM described current and projected climate trends and analyzed how these trends could affect the resources described in other sections. The BLM then considered the extent to which the alternatives and the Proposed RMP would allow BLM to consider actions that promote adaptation to climate change during the implementation of the RMP.

The potential climate change impacts of most concern to the BLM are the indirect effects of changes in temperature, precipitation, and snow within the planning area, as these factors affect forest productivity and species composition, habitat for terrestrial and aquatic wildlife, and key disturbance regimes. This analysis focuses on the possible impacts to tree species composition and growth, fire regimes, insect outbreaks, certain diseases such as Sudden Oak Death and Swiss needle cast, stream flow and temperature in the context of fish habitat, and habitat for old growth-associated species such as northern spotted owl and marbled murrelet.

The Planning Criteria provides more detailed information on analytical assumptions, methods and techniques, and geographic and temporal scales, which is incorporated here by reference (USDI BLM 2014, pp. 39–40). The existing analyses in the NatureServe Climate Change Vulnerability Index website (2014) did not include any species of birds, fish, or mammals relevant to BLM-administered lands in the planning area as of September 3, 2014. The bulk of this analysis consists of a review and synthesis of key literature.

To assess observed changes in climate, the BLM elected to use temperature and precipitation data available through WestMap (2014), a tool developed by the Desert Research Institute, extracting the data by three hydrologic units: the Willamette River basin, Oregon coastal basins, which include southwest Oregon, and the Klamath River Basin. Data for the Klamath River basin includes northern California. Data extracted included precipitation, average temperature, average maximum temperature, and average minimum temperature, both annually and seasonally. The BLM used the water year (October 1 to September 30) for the annual basis and meteorological/climatological seasons (winter = December to February, spring = March to May, summer = June to August, and fall = September to November). The BLM imported the data into Excel spreadsheets, summarized, and conducted linear trend analyses using Sigma Plot 12.3. The BLM considered the results statistically significant at P-values of 0.05 or less. The BLM also extracted snow course data from the Natural Resources Conservation Service website (NRCS 2014) and evaluated long-term trends in April 1 snow water equivalent using an Excel spreadsheet. The BLM did not analyze these data for statistical significance.

Background

Global assessments of climate over time have increased the certainty that climate is changing and that humans are a primary cause of that change through emissions of greenhouse gases, carbon dioxide in particular (IPCC 2013). According to the latest assessment from the Intergovernmental Panel on Climate Change (IPCC) global temperatures have increased by 1.53 ºF since 1880; the number of cold days and nights have decreased while the number of warm days and nights have increased; the frequency and intensity of heavy precipitation events have increased in North America and Europe; glaciers, sea ice, major ice sheets, and spring snow cover continue to shrink; and atmospheric concentrations of carbon dioxide, methane, and nitrous oxide exceed those of the last 800,000 years (IPCC 2013).

The latest national assessment for the United States affirms these same general trends. Average temperature in the United States has increased 1.3 to 1.9 ºF, with most of this increase since 1970. The year 2012 was the warmest year on record. The length of the frost-free season has decreased and the subsequent growing season increased; heavy downpours have increased in frequency over the last three to five decades; heat waves are more frequent and intense, while cold waves are less frequent and less intense; winter storms have increased in frequency and intensity since the 1950s, and the general track has shifted northward; glaciers and snow cover are shrinking (Walsh *et al.* 2014).

The Pacific Northwest (Oregon, Washington, Idaho, and western Montana) has experienced many of the changes noted globally and nationally. The Pacific Northwest has warmed by 1.3 ºF since 1895, with statistically significant warming in all seasons except spring, lengthening the frost-free period by 35 days (Snover *et al.* 2013, Abatzoglou *et al*. 2014). Spring precipitation has increased while summer and fall precipitation have decreased; with increasing potential evapotranspiration, the climatic water deficit has also increased (Abatzoglou *et al*. 2014). The frequency of extreme high nighttime temperatures has increased, with a statistically significant increase west of the Cascade Mountains; however, no clear change in other temperature extremes has emerged (Dalton *et al.* 2013, Snover *et al.* 2013). Annual precipitation has no clear trend either upward or downward, with high interannual variability (Snover *et* *al.* 2013). Although annual snowpack also fluctuates widely, snow accumulation is generally declining, and spring snowmelt is occurring earlier, leading to an earlier peak in streamflow in snowmelt-influenced streams (Snover *et al.* 2013).

Affected Environment

Three different climate types characterize the planning area: maritime, Mediterranean, and continental. The Coos Bay, Eugene, and Salem Districts have a maritime climate, typified by relatively cool, moist conditions year-round, although the Willamette Valley can be quite warm and dry in summer. The western portion of the Klamath Falls Field Office and the Medford District have a Mediterranean climate, characterized by cool to warm, moist conditions in winter and hot, dry conditions in summer. The eastern portion of the Klamath Falls Field Office has a continental climate, with cold, dry winters and hot, dry summers. The Roseburg District encompasses a transition zone between the Mediterranean and maritime climates, with no clear demarcation between the two climate types.

Based on the WestMap data, annual precipitation increased slightly in the Willamette River, Oregon Coastal and Klamath River basins since 1896, and in some seasons, although the increases were not statistically significant (**Figure 3-20**). The one exception is a statistically significant increase in spring precipitation in the Willamette River and Klamath River basins. All basins show a statistically non-significant decline in fall precipitation, and the Oregon coastal basins have a statistically non-significant decrease in winter precipitation.

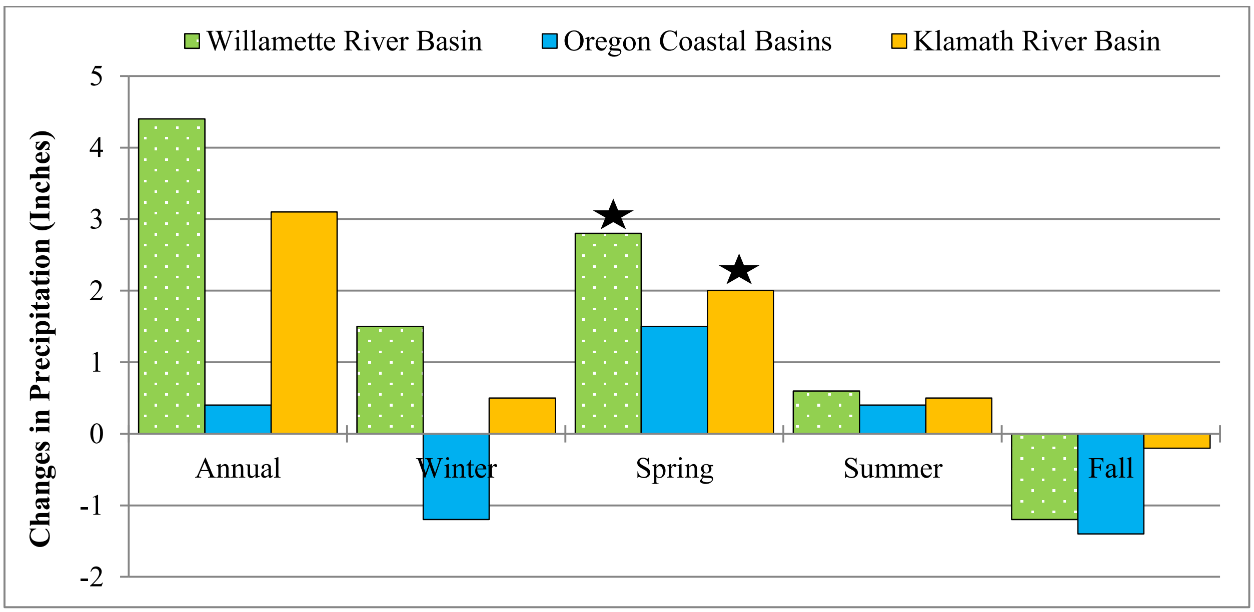

Figure 3-20. Observed changes in annual and seasonal precipitation by basin
Note: A star indicates change is statistically significant; Annual = October 1–September 30, Winter = December–February, Spring = March–May, Summer = June–August, Fall = September–November

The WestMap data also indicate that average annual and seasonal temperatures have experienced statistically significant increases across the planning area (**Figure 3-21**). Since 1896, average annual temperature has increased by 1.4 ºF in the Oregon coastal basins, by 1.6 ºF in the Willamette River basin, and by 1.8 ºF in the Klamath River basin. Increases in average spring temperature are not statistically significant in the Willamette River and Klamath River basins. Increases in minimum temperatures are statistically significant in all basins, both annually and seasonally, whereas increases in maximum temperatures are significant only annually and in winter in all basins. The increase in summer temperature is also statistically significant in the Klamath River Basin. Increases in minimum temperature are greater than the increases in maximum temperature. Given the small increases in precipitation and the more statistically significant increases in temperature, the entire planning area is becoming warmer and drier, particularly in winter and at night. The amount of effective change in the Willamette River basin is smaller than the change in the Oregon coastal basins and Klamath River basin.

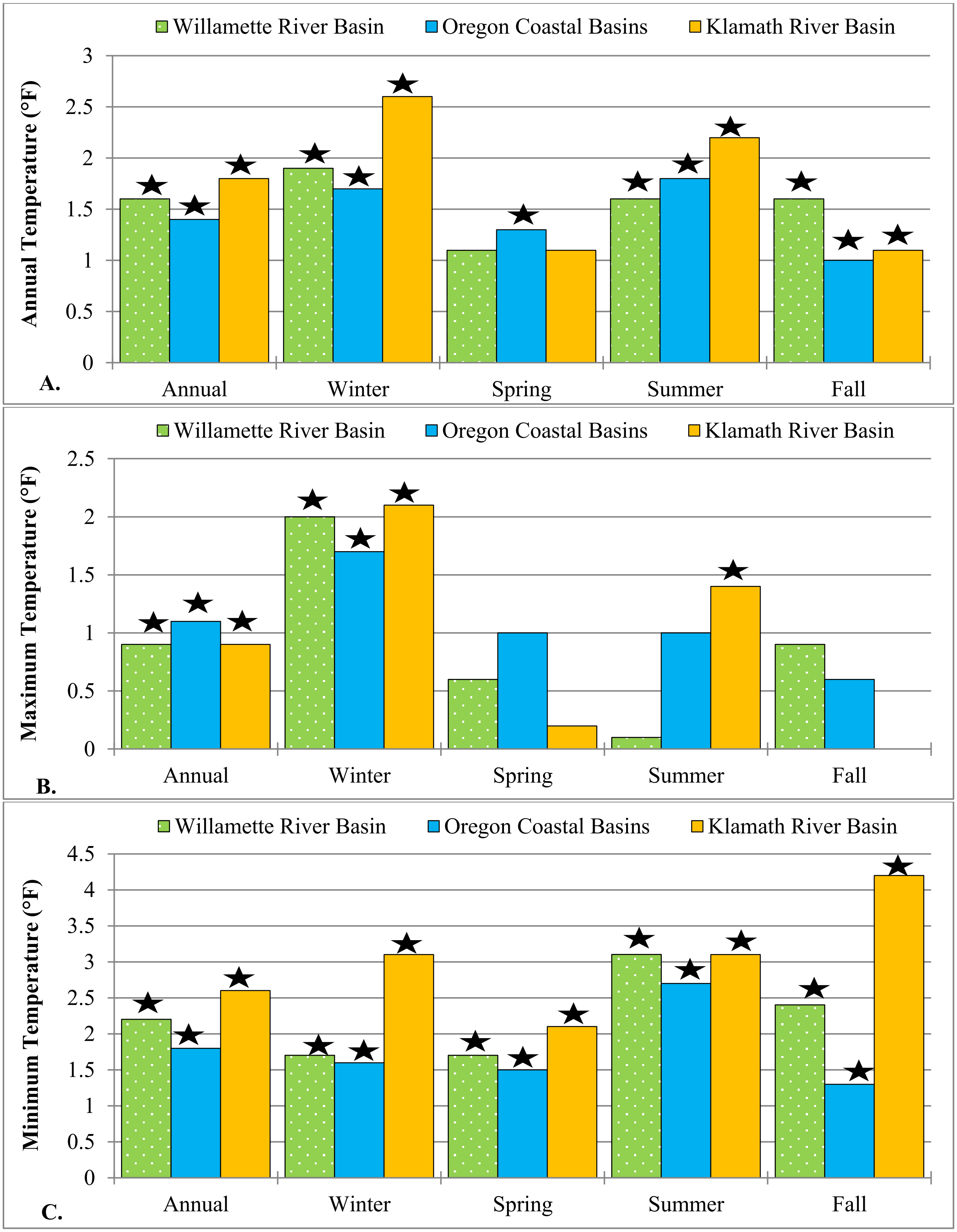

Figure 3-21. Observed changes in (a) annual, (b) maximum, and (c) minimum temperature in each basin

Note: A star indicates the change is statistically significant; Annual = October 1–September 30, Winter = December–February, Spring = March–May, Summer = June–August, Fall = September–November

Winter precipitation, in particular the amount, type, and timing, is an important factor in the response of vegetation and streams to climate change (Dalton *et al.* 2013, Peterson *et al.* 2014). Winter precipitation typically falls as rain in the coastal mountains and western Oregon valleys and a mix of rain and snow in the Cascade foothills and mountains (Safeeq *et al.* 2013, Klos *et al.* 2014). In the Cascades, only small differences in temperature differentiate between a rain event and a snow event (Lute and Abatzoglou 2014). Interactions between the phase of El Niño-Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO) influence winter temperatures and precipitation, resulting in high interannual variability in winter precipitation amount and timing (Dalton *et al*. 2013, Lute and Abatzoglou 2014). El Niño winters (ENSO warm phase) typically result in 20–60 percent less snow, while La Niña winters (ENSO cool phase) typically result in 30–70 percent more snow (Lute and Abatzoglou 2014). The larger differences tend to occur when the phases of ENSO and PDO align (Dalton *et al.* 2013).

Reflecting the observed changes in temperature in particular, April 1 snow water equivalent (the time when snowpack historically has peaked) has been decreasing across much of the western United States, with some of the largest relative decreases in western Oregon (Mote *et al.* 2005, Peterson *et al.* 2014). Snow course data for western Oregon indicate that decreases are occurring at all elevations across the planning area, although there is high interannual variability in snow amounts. Both the Cascade and Klamath Mountains can have high accumulations of snow, but that accumulation period is typically short, and the snowmelt period begins early and occurs more rapidly that most of the western United States (Trujillo and Molotch 2014). In contrast, the Coast Range has only intermittent snow all winter. Winter atmospheric rivers, often associated with La Niña winters, typically deliver the most snow and over short periods (1–2 days), but can also result in rain-on-snow events that result in very rapid melting and flooding (Lute and Abatzoglou 2014, Trujillo and Molotch 2014).

Thus far, the observed changes in climate have not yet lead to obvious changes in forests, most disturbance regimes, and terrestrial wildlife species ranges or habitat within the planning area, although subtle changes could well be happening. Assessments at larger spatial and temporal scales suggest some changes could be occurring already, but at levels indistinguishable from natural variability. In other words, within the planning area, climate-related changes in ecosystems cannot be detected over the "noise" of interannual and interdecadal variability at this geographic scale. Apparent temporal disconnects between changes in climate and changes in vegetation are common; older forests in particular experience such disconnections as established vegetation is able to tolerate larger changes in climate than seedlings.

Tree Species

In their evidence-based review of the science, Allen *et al.* (2010) found that tree mortality from climate-induced stress driven by drought and warmer temperatures appears to be increasing worldwide in all forest types. In North America, drought and warmer temperatures have been correlated to increases in the mortality of several pine species, several spruce species, white fir, incense cedar, two species of juniper, and Douglas-fir (Allen *et al.* 2010). In the western United States, background rates of mortality have increased in recent decades across elevation, tree size, dominant genera, and past fire histories with warming and increased water stress believed to be a major contributor to the increase (van Mantgem *et al.* 2009, Smith *et al.* 2015). The patterns of mortality are patchy with higher levels in drier forests, but increased mortality has been documented on productive sites where changes in moisture stress may well interact with density-dependent factors (Allen *et al.* 2010). In conifer forests and woodlands, climate-related mortality is more common during multi-year droughts than during seasonal droughts, and warmer temperatures can increase moisture stress independent of precipitation amount (Allen *et al.* 2010). Given these findings, climate change may have increased background tree mortality in the Klamath Falls Field Office and the Medford and Roseburg Districts, but it is less clear if background mortality may have increased in the Coos Bay, Eugene, and Salem Districts.

Devine *et al.* (2012) developed climate vulnerability rankings for major tree species U.S. Forest Service lands in Oregon and Washington, breaking out the results by geographic area. The authors based the ratings on tree species distribution, reproductive capacity, habitat affinity, adaptive genetic variation, and risk of insects and disease. Species deemed more vulnerable were those that are rare, have low seed production and low seed viability with very short dispersal distances, are habitat specialists, are either disjunct or at the edge of the species' range, and have insect pests or diseases that are increasing in distribution and impacts with typically high mortality of mature trees, among other characteristics. Species rated as less vulnerable are those with opposite characteristics (e.g., widespread, common, habitat generalists, and high seed production with high seed viability). The rankings used data on the distribution of species on U.S. Forest Service lands, although the rankings provide an indicator of potential vulnerability on BLM-administered lands within the planning area. The authors normalized rankings so they vary between 0 and 100, with the higher the ranking, the more vulnerable the species.

Rankings sometimes differ for species that occur in both northwest and southwest Oregon (**Table 3-15**). For example, the authors rated Engelmann spruce as less vulnerable in northwest Oregon than in southwest Oregon, whereas the opposite was true for sugar pine. The authors rated Douglas-fir as slightly more vulnerable in northwest Oregon than in southwest Oregon, largely due to differences in adaptive genetic variation and insects and disease risks. Generally, species found primarily at higher elevations tended to be ranked as more vulnerable than those found primarily at lower elevations. Some species may be more widespread on BLM-administered lands, which tend to be lower elevation, than on U.S. Forest Service lands, and therefore may actually have a somewhat lower vulnerability, whereas the opposite may also be true for other species. Examples of the former would be the various oak species, while the latter would be the higher elevation species.

Table 3-15. Climate change vulnerability scores for different tree species in western Oregon

Species	Northwest Oregon	Southwest Oregon
Subalpine fir	77	69
Pacific silver fir	66	56
Noble fir	60	-
Noble fir-Shasta red fir complex	-	48
Grand fir	59	-
Grand fir-white fir complex	-	55
Douglas-fir	41	36
Western hemlock	52	42
Western larch	52	-
Engelmann spruce	55	71
Sitka spruce	39	-
Whitebark pine	67	67
Lodgepole pine	56	42
Shore pine	17	-
Sugar pine	59	39
Ponderosa pine	46	46
Western white pine	39	36
Jeffrey pine	-	39
Knobcone pine	-	30
Western redcedar	36	35
Alaska yellow-cedar	59	-
Port-Orford-cedar	36	35
Incense-cedar	-	33
Western juniper	-	27
Bigleaf maple	50	39
Red alder	38	33
Tanoak	-	46
Oregon white oak	54	48
California black oak	-	45
Canyon live oak	-	40
Black cottonwood	27	-
Pacific madrone	-	46

Note: A higher score indicates greater vulnerability. In Devine *et al*. 2012, Northwest Oregon roughly corresponds to the Eugene, Roseburg, and Salem Districts, Southwest Oregon to the Coos Bay and Medford Districts and the Klamath Falls Field Office.
Source: Devine *et al*. 2012

One factor in the ratings is whether the species is at or near the limits of its range, although it is not clear if the authors rated species at the southern end of their range differently than species at the northern limit. A common climate change effect prediction is that species ranges would tend to shift poleward and upward in elevation; numerous studies of taxa other than trees have documented shifts consistent with this prediction (e.g., Parmesan and Yohe 2003, Root *et al.* 2003, Tingley *et al.* 2012, Comte and Grenouillet 2013, and Cahill *et al.* 2014). Pacific silver fir, subalpine fir, Alaska yellow-cedar, and Engelmann spruce are at or near the southern limits of their range in western Oregon, so may well be more vulnerable in southwestern Oregon. Conversely, incense-cedar, sugar pine, Jeffrey pine, canyon live oak, California black oak, and tanoak are at the northern limits of their range in western Oregon and could be expected to expand northward, making them less vulnerable.

Insects and Pathogens

Many insects and pathogens are influenced by temperature and precipitation amount and timing (Sturrock *et al.* 2011, Vose *et al.* 2012, Peterson *et al.* 2014). Sturrock *et al.* (2011) reviewed much of the literature concerning the potential impact of climate change on a variety of important forest diseases. Generally, warming winters and minimum temperatures and increasing moisture during the growing season will favor pathogens that require leaf or needle wetness to spread, while drying conditions disfavor such pathogens. Examples include Sudden Oak Death (Venette and Cohen 2006), *Dothistroma* needle blight (Woods *et al.* 2005), Swiss needle cast (Manter *et al.* 2005, Lee *et al.* 2013, Tillmann and Glick 2013), and white pine blister rust (Sturrock *et al.* 2011). Although not specifically discussed, Port-Orford-cedar root disease, another *Phytophthora* species, likely responds similarly to Sudden Oak Death. In contrast, warming and drying conditions will favor pathogens that increase when host species are water-stressed, such as *Armillaria* root disease and various canker species (Sturrock *et al.* 2011, *Vose et al.* 2012). The response of pathogens that depend on insects for spread will likely be complex, depending on how the particular insect vector responds to changing climate (Sturrock *et al.* 2011).

Since temperature is a primary control on insect development and survival (Peterson *et al.* 2014), warming temperatures will and are altering insect pest dynamics (Chmura *et al.* 2011). The best-known and documented example is mountain pine beetle with the recent outbreak across western North America the subject of many studies. Warming temperatures and increased drought stress are commonly cited factors in the scale of the current mountain pine beetle outbreak (Vose *et al.* 2012). Conditions that create water stress in trees limit the effectiveness of tree defenses and favors bark beetles (Evangelista *et al.* 2011, Vose *et al.* 2012, Tillmann and Glick 2013, Creeden *et al.* 2014). How changing climate is now affecting and will potentially affect defoliating insects is less clear. Outbreaks of this class of insects tend to be cyclical and involve predators, parasitoids, and pathogens of the individual insect species, and the role of climate in such cycles is not clear (Vose *et al.* 2012, Tillmann and Glick 2013). For example, outbreaks of western spruce budworm in the interior west tend to occur near the end of droughts (Flower *et al.* 2014), but in British Columbia tend to be associated with dry winters followed by average spring temperatures (Campbell *et al.* 2006). Chen *et al.* (2003) noted that the degree of damage in Douglas-fir was also correlated with close matches between the phenology of budburst and larval emergence. Changing atmospheric CO_2 concentrations will also influence insect dynamics by increasing carbon availability for tree defenses and altering the carbon:nitrogen ratios in leaves and needles, thereby reducing food quality (Peterson *et al.* 2014). Reduced food quality can lead to increased herbivory in order to obtain the amount of nutrients needed to complete insect life cycles.

Other than a documented increase in the incidence, damage, and inland spread of Swiss needle cast in northwest Oregon (Manter *et al.* 2005), no obvious climate change-related changes in the incidence of insects and diseases have been clearly noted within the planning area. Determining both whether increasing atmospheric CO_2 has a bigger impact than increasing temperature and whether the effects of increasing atmospheric CO_2 concentrations on insect dynamics has occurred within the planning area remains elusive.

Wildfire

Many studies have examined changes in area burned, individual fire severity, and fire season severity, concluding that changes in climate are a major factor driving these observed changes. Westerling *et al.* (2006) documented an increase in the length of fire season in the western U.S. by at least one month, based on start dates of fires at least 1,000 acres in size, attributing this change to earlier snowmelt and longer, drier summers. Van Mantgem *et al.* (2013) reported an increase in the probability of tree mortality due to the combination of drought and warming temperatures. Dry, warm conditions, particularly in the years of fire, are also strongly associated with greater annual area burned in the northwestern United States (Littell *et al.* 2009). Larger wildfires in recent decades also tend to have a higher proportion of high severity burn area in terms of tree mortality, and larger high severity patch sizes when conditions are warm and dry (Abatzoglou and Kolden 2013, Cansler and McKenzie 2013).

Within the planning area, fire season length and potential severity, as measured by energy release component, a measure of seasonal dryness used in fire danger rating, has increased (Dalton 2014; unpublished data). The changes in fire season severity and the severity of individual wildfires have occurred in the Northwest consistent with the results above for the western U.S.; however, there are simply too few wildfires that have originated on BLM-administered lands (or in western Oregon), to provide a clear signal of such changes. An analysis of large fires across the entire state of Oregon using data from the Monitoring Trends in Burn Severity site (MTBS 2013) indicates that the proportion of high-severity fire in forests generally has increased by 11 percent since 1984, with much of the increase since 2000.

Streamflow and Temperature

Several studies have concluded that observed changes in stream flow regimes and temperature in the western U.S. are a result of climate change, but that these changes depend on more than just changes in air temperature, precipitation amount, and timing. Geology, topography, vegetation, and other factors also play a role (Dalton *et al.* 2013, Safeeq *et al.* 2013). Safeeq *et al.* (2013) report that streams that are primarily groundwater-sourced respond differently to changing climate from those that are surface water-sourced. In western Oregon, streams arising in the Coast Range are surface water-sourced from rain, whereas streams arising in the Cascades are groundwater-sourced from a mix of rain and snow, with predominately rain below 1,300 feet elevation, predominately snow above 4,900 feet, and a mix of rain and snow between 1,300 and 4,900 feet (Tague and Grant 2004, Safeeq *et al.* 2013, Klos *et al.* 2014). Total annual streamflow has been declining in the Pacific Northwest and current flows are similar to those in the 1930s, one of the driest periods on record (Luce *et al.* 2013). While scientists do not understand the exact causes, some combination of warming temperatures, decreasing snow, and decreasing mountain precipitation due to weakening of the westerly winds in winter appear to play a role (Dalton *et al.* 2013, Luce *et al*. 2013, Berghuijs *et al.* 2014).

The timing of peak flows is also shifting across the western U.S. with an increased proportion of the annual flow occurring in winter and a decreasing proportion in summer (Safeeq *et al.* 2013). Rain-dominated streams have earlier peak spring flows and declining late fall and winter flows, whereas snow-dominated streams have greater reductions in summer flows (Safeeq *et al.* 2013). However, the response of individual streams varies, depending on underlying geology. For example, streams originating in geology that supports slow-draining, deep groundwater exhibit less variability in flow regimes than streams originating in geology that supports shallow, rapid subsurface flow (Tague and Grant 2004 and 2009). However, as snowpack declines, the absolute change in summer base flows is greater in the deep groundwater systems than in the shallow, rapid subsurface systems (Tague *et al.* 2008, Tague and Grant 2009, Safeeq *et al.* 2013).

Stream temperatures in the United States as a whole and in the Northwest have been increasing (Bartholow 2005, Kaushal *et al.* 2010, Dalton *et al.* 2013). However, there is local and regional variation. Kaushal *et al.* (2010) reported statistically significant upward trends for Fir Creek, the North Santiam River and Rogue River, statistically non-significant trends for the Bull Run, South Fork Bull Run, and North Fork Bull Run rivers, and no trend for the South Santiam River. Blue River had a statistically significant cooling trend, although all records for Oregon were relatively short. The direction and significance of stream temperature trends depend on the period of record, sample size, and spatial extent of the samples (Arismendi *et al.* 2012).

Northwest streams typically have cooling trends in spring, consistent with increasing precipitation, but warming temperatures in summer, fall, and winter. The cooling in spring is not enough to fully offset warming in the other seasons, leading to an overall warming trend in stream temperatures (Isaak *et al.* 2012). The rates of warming are highest in summer, with greater summer warming occurring in streams with the largest decrease in discharge instead of the streams with the lowest discharge (Isaak *et al.* 2012). Overall, stream temperatures track with air temperatures, although there is often a slight lag (Isaak *et al.* 2012, Arismendi *et al.* 2013). Diabat *et al.* (2013) found that increasing nighttime temperatures appears to be a bigger driver of stream temperature changes than increasing daytime temperatures, indicating that the observed increasing minimum temperatures in all seasons may be important factors. In the John Day River in eastern Oregon, the time lag between stream temperature maxima and stream flow minima has decreased by approximately 24 days since 1950, potentially due to earlier timing of stream flow minima, especially given no observed change in the timing of stream temperature maxima (Arismendi *et al.* 2013). Similar changes are likely within the planning area, given that the same air temperature and stream flow changes are occurring across Oregon.

Wildlife and Wildlife Habitat

Several different studies have documented changes in fish and wildlife species consistent with those expected with increasing temperatures worldwide, nationally, and statewide. These observed effects include changes in migration timing, species ranges, species abundance, and similar impacts (Parmesan and Yohe 2003, Hixon *et al.* 2010, Tillmann and Glick 2013, Groffman *et al.* 2014). Detailed discussion of any observed climate change effects on all fish and wildlife species found within the planning area is not possible. However, a brief discussion of climate influences on northern spotted owl and marbled murrelet illustrates how climate change may be influencing two important species.

Climate can affect species persistence directly by affecting survival of the young and indirectly by altering habitat, such as nesting sites or prey abundance. With northern spotted owls, climate conditions that affect prey abundance affect owl survival, with populations decreasing when winters and early spring were cold, wet and stormy or summers are droughty, and populations increasing when late spring through early fall are moist (Franklin *et al.* 2000, Glenn *et al.* 2010, Glenn *et al.* 2011). In Cascade populations, owl survival also decreases as the number of summer days with temperatures at or above 90 ºF increases (Glenn *et al.* 2010, Glenn *et al.* 2011). Under stable habitat conditions, climate is apparently the dominant influence on owl populations, but as habitat quality declines, the effects of climate variation on survival increases (Franklin *et al.* 2000). Climate effects appear to be local, rather than regional, with some locations experiencing lags in effect with respect to sub-adult survival (Glenn *et al.* 2010, Glenn *et al.* 2011).

Marbled murrelets are affected by both land and ocean conditions. Various studies have attributed population declines in the 1990s and 2000s to loss of nesting habitat and low food availability at sea (Strong 2003, Peery *et al.* 2004, Becker *et al.* 2007, Norris *et al.* 2007, Miller *et al.* 2012b, Raphael *et al.* in press), but disagree on which is more important. Poor ocean conditions arising from climate may have contributed to murrelet population declines in the 1990s by affecting food availability at sea, but given improved ocean conditions since the mid-2000s, climate may not have been a substantial factor in continued declines. Raphael *et al.* (2015) found that at the current low murrelet population levels, much of the ocean habitat with apparently suitable forage conditions is presently unused, but also that access to finer-scaled spatial and temporal conditions may have increased their ability to detect marine influences on murrelet at-sea distributions. Norris *et al.* (2007) found that since the 1950s, murrelet populations in southern British Columbia were adversely affected by low food quality, specifically by less abundance of small fish in the bird's diet. Off the central California coast, Becker *et al.* (2007) found that murrelet productivity was correlated with rockfish and krill productivity, which were higher when ocean temperatures were cooler. When food resources are low, murrelet adults must fly further and dive more often, using more energy (Peery *et al.* 2004). As with northern spotted owls, these findings indicate that even when sufficient high-quality nesting habitat is available, climate events and climate change can influence murrelet populations by affecting the conditions important for prey species.

Climate Change Projections and Potential Effects on Resources

Dalton *et al.* (2013) summarized the most recent climate change projections for the Pacific Northwest (Oregon, Washington, Idaho, and western Montana) under representative concentration pathways (RCP) 4.5 and 8.5. These pathways represent a substantial reduction in greenhouse gas emissions in the near future and "business as usual," respectively. Current greenhouse gas concentrations and atmospheric CO_2 concentrations are tracking with the RCP 8.5 pathway (Peters *et al.* 2013, Le Quéré *et al.* 2014). By 2041–2070, temperatures are projected to increase in all seasons, with the largest increase in summer (**Table 3-16**). Precipitation is projected to increase modestly in winter, spring and fall and decrease in summer throughout the Pacific Northwest. The area west of the Cascades where the maritime influence is strong would not warm as much as elsewhere in the Pacific Northwest, particularly in spring. Dalton *et al.* (2013) did not identify any sub-regional differences in precipitation.

Table 3-16. Expected changes in mean annual and seasonal temperature and precipitation by 2041–2070 as compared to means in the 1950–1999 for RCP 4.5 and RCP 8.5

Season	Temperature		Precipitation	
	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Annual	4.3 ºF (2.0–6.7 ºF)	5.8 ºF (3.1–11.5 ºF)	+2.8% (-4.3–10.1%)	+3.2% (-4.7–19.8%)
Winter (Dec.–Feb.)	4.5 ºF (1.0–7.2 ºF)	5.8 ºF (2.3–9.2 ºF)	+5.4% (-5.6–16.3%)	+7.2% (-10.6–19.8%)
Spring (Mar.–May)	4.3 ºF (0.9–7.4 ºF)	5.4 ºF (1.8–8.3 ºF)	+4.3% (-6.8–18.8%)	+6.5% (-10.6–26.6%)
Summer (Jun.–Aug.)	4.7 ºF (2.3–7.4 ºF)	6.5 ºF (3.4–9.4 ºF)	-5.6% (-33.6–18%)	-7.5% (-27.8–12.4%)
Fall (Sep.–Nov.)	4.0 ºF (1.4–5.8 ºF)	5.6 ºF (2.9–8.3 ºF)	+3.2% (-8.5–13.1%)	+1.5% (-11.0–12.3%)

Note: Ranges are in parentheses

Some of the projected changes displayed in **Table 3-16** are not consistent with observed trends displayed in **Figure 3-20** and **Figure 3-21**, with differences in precipitation especially notable. Climate models project an increase in fall precipitation, yet the observed trend is a decrease. Similarly, the observed trend in summer precipitation is a slight, statistically insignificant increase, whereas the projection is for a decrease. Observed and projected temperature changes are more consistent, but the magnitude of change shows some differences. For example, the observed increase in maximum summer temperatures in the Willamette basin is small; suggesting that the mid-century increase may not be as large as projected.

The differences between the projections and observed trends likely arise due to differences in the size of area assessed and resolution of the data used. Trends in a smaller part of the Pacific Northwest can differ from those for the area as a whole. The WestMap data are at a finer resolution than the climate projection data, so likely better reflects the effects of topography on both temperature and precipitation. The projected changes in precipitation in particular encompass large ranges, including both increases and decreases in all seasons in both climate change scenarios, even though the ensemble mean indicates increases in winter, spring, and fall and decreases in summer. Lastly, observed trends in precipitation may not continue in the future if increasing temperatures result in fundamental changes in the atmospheric circulation patterns that bring moist air into Oregon.

By 2041–2070, the number of frost-free days is projected to increase by 35 days (± 6 days) relative to 1971–2000. Climate modeling indicated the number of growing degree-days using a base of 50 ºF would increase by 51 percent (± 14 percent). The number of hot days (i.e., days with maximum temperatures greater than 90 ºF, 95 ºF and 100 ºF, as well as the number of consecutive days above 95 ºF and 100 ºF) would increase, while the cold days (with minimum temperatures of less than 32 ºF, 10 ºF, and 0 ºF) would decline. The number of very wet days (with precipitation above 1 inch, 2 inches, 3 inches, and 4 inches) would increase, as would the dry spells (maximum run of days with less than 0.1 inch).

As temperatures continue to warm, the extent of snow-dominated winter precipitation would continue to decline (Mote *et al.* 2005). By mid-century, none of the Cascades ecoregion (EPA Level-III ecoregion 4) would remain strongly snow-dominated, and the extent of strongly rain-dominated area would increase by 42 percent to an estimated 59 percent of the ecoregion. Although none of the Coast Range (EPA Level-III ecoregion 1) and the Klamath Mountains (EPA Level-III ecoregion 78) are strongly snow-dominated, all of the Coast Range and 95 percent of the Klamath Mountains are projected to become strongly rain-dominated by mid-century (Klos *et al.* 2014).

Several different climate change assessments project that the frequency, duration, and severity of drought will increase globally, nationally, and regionally (Dai 2011, Gutzler and Robbins 2011, Jung and Chang 2012, Vose *et al.* 2012, Dalton *et al.* 2013, Walsh *et al.* 2014). However, the term 'drought' remains ill-defined, making projections of changing drought risks difficult to evaluate. Drought is not just a deficit in precipitation, but insufficient water to meet needs. Temperature plays a very important role that many drought assessment tools either do not incorporate or incorporate inadequately (Bumbaco and Mote 2010). Three different types of drought occur in the Pacific Northwest (Bumbaco and Mote 2010) and more than one kind of drought can occur in a given year. The first type is very low winter precipitation with seasonally typical temperatures (dry drought), as represented by conditions in 2001. The second type of drought consists of warm winter temperatures with normal precipitation, resulting in more rain and low snow packs, followed by a very warm, dry summer (hot-dry drought), as represented by conditions in 2003. This type of drought can develop suddenly with little or no warning and is associated with low summer streamflow in western Oregon. The third type of drought consists of a warm, dry winter followed by a near normal summer (warm-dry drought), as represented by conditions in 2005. A characteristic of all these drought types is a low winter snowpack combined with high evapotranspiration demand during the growing season. The warm-dry drought and hot-dry drought are also associated with more severe fire seasons in western Oregon. Based on the temperature and precipitation projections, Northwest climate scientists expect the warm-dry and hot-dry drought types will increase in frequency while the dry drought type will likely decrease in frequency (Bumbaco and Mote 2010).

A particular emerging concern among forest scientists who study climate change is the increasing role of drought in tree and forest mortality (e.g., Allen *et al*. 2015 and references therein, McDowell and Allen 2015, and Millar and Stephenson 2015 and references therein). Variously called 'global-change-type drought', 'hot drought', and 'hotter drought', the focus is the role higher temperatures play in increasing drought intensity and severity, tree and forest water stress, and subsequent tree vulnerability to insects, pathogens, and fire (Allen *et al*. 2015, Millar and Stephenson 2015). While the most severe effects have occurred in semi-arid forests, scientists are increasingly concerned about the vulnerability of temperate forests (Millar and Stephenson 2015). There is scientific disagreement on just how vulnerable these forests are (Allen *et al*. 2015). In a review paper, Allen *et al*. (2015) identified six global vulnerability drivers:

- Droughts eventually occur everywhere
- Warming produces hotter droughts
- Atmospheric moisture demand increases nonlinearly with temperature during drought
- Mortality can occur faster in hotter drought
- Shorter droughts occur more frequently than longer droughts and can become lethal under warming, increasing the frequency of lethal drought nonlinearly

- Mortality happens rapidly relative to growth intervals needed for forest recovery

These so-called hotter droughts could increase tree mortality in western Oregon in the future. These hotter droughts could also affect cold-water fish and aquatic organisms, species that depend on cooler temperatures, and species that depend on relatively frequent rain in summer.

There are substantial uncertainties associated with the various predictions discussed below. The choice of global climate model used is typically the largest source of variability in simulation study results (Hurteau *et al.* 2014). There is also a fundamental scale mismatch between the spatial resolution of climate predictions, even those that have been downscaled, and the size of the typical management unit simulated in many studies (Hurteau *et al.* 2014).

Tree Species

Understanding how climate change may affect species composition and forest productivity has been the topic of numerous studies. Results vary depending on the spatial and temporal scale of the studies and assumptions about climate drivers and the interaction between climate and non-climate drivers that underpin such studies. Therefore, interpreting what these results might mean for land management remains challenging. Generally, trees can respond to changing climate through phenotypic plasticity (altering physiology), morphology, and reproduction within their existing genetic capability, through natural selection, or through migration, as summarized by Peterson *et al.* (2014, Chapter 5).

There are several approaches to modeling potential vegetation change based on statistics, ecological processes, or a mix of the two, all with their strengths and weaknesses (Peterson *et al.* 2014, Chapter 6). Most studies of how tree species compositions may shift use bioclimatic envelope models, a statistical method that bases predictions on the climate where species are present and absent. Despite their limitations, bioclimatic envelope models are the most widely used, due to ease of use and applicability at a number of scales (Araújo and Peterson 2012, Peterson *et al.* 2014). Other factors, such as competition, land uses, soils, topography, and disturbance regimes, can prevent a species from occupying an area that is otherwise suitable climatically, or allow it to remain in a location that broader-scale climate predictions indicate would not remain suitable (Peterson *et al.* 2014). Process-based models and hybrid models can incorporate many non-climate drivers. However, these models remain rarely used to date, due to the lack of information needed to parameterize such models for most species, high computational demand, and lack of information on how climate affects many forest tree processes, particularly regeneration, growth, and mortality (Peterson *et al.* 2014).

Using the climate module of the Forest Vegetation Simulator (Climate-FVS), the climatically suitable area for many important timber species in the planning area would contract by mid-century, primarily from the lower elevations, with generally much greater contraction under RCP 8.5 than under RCP 4.5 (Diaz et al. 2014). The suitable climate for western hemlock, western redcedar, Pacific yew, incense cedar, Port-Orford-cedar, grand fir, white fir, noble fir, and sugar pine are projected to contract substantially in western Oregon under both pathways. Several modeling approaches indicate probable loss of climatically suitable areas for western hemlock and western redcedar, primarily in southwest Oregon, but the projected losses from Climate-FVS are likely too high (Diaz et al. 2014). The area climatically suitable for Douglas-fir may increase in the Klamath Falls Field Office. The Climate-FVS analysis projected that the climatically suitable area for several species more typically found in California, such as several species of oak, white alder, California laurel, and knobcone pine would expand into Oregon and up the eastern side of the Coast Range and foothills of the Cascades.

The fate of Douglas-fir is of particular interest due to its current dominance throughout western Oregon and importance for both timber and wildlife habitat. Many studies predict some degree of decline in the extent of Douglas-fir, particularly at lower elevations. The degree of decline varies widely between studies, ranging from major contractions, especially from the Coast Range, to little change (Bachelet *et al.* 2011 and references therein, Coops and Waring 2011, Peterson *et al.* 2014, Rehfeldt *et al.* 2014a).

Using the dynamic global vegetation model MC2, Bachelet (2014 in Diaz *et al.* 2014) projected substantial contraction of the maritime conifer forest and expansion of both the temperate conifer forest more typical of eastern Oregon and temperate cool mixed forest more typical of the central and southern Coast Range (data available at DataBasin 2014). Using MC1, Rogers *et al*. (2015 and references therein) also projected a contraction of the highly productive maritime conifer forests and expansion of the lower productivity warm temperate and subtropical mixed forests in western Oregon by the end of the century, although the degree of change varied by climate model. Douglas-fir is a substantial component of all three forest types, but consists of different ecotypes, or climatypes,[43] of the species (Rehfeldt *et al.* 2014c). In addition, the temperate cool mixed-conifer forest type includes a number of so-called hardwoods, such as tanoak, madrone, and several species of oaks, suggesting broad consistency between the statistical approach used by Climate-FVS and the process-based approach used in MC1 and MC2.

With shifting bioclimate suitability, a primary concern is the rate at which climate is changing (climate velocity), relative to the rate at which a given species can migrate. For plants, migration rates depend on seed production rates, seed dispersal distances, average seed viability, presence or absence of barriers, biotic interactions between migrating species and current species, and the presence of suitable habitat between the current location of a given climatype and the likely future location of suitable climate (Peterson *et al.* 2014). Climate velocity is generally slower in complex terrain, and complex terrain is more likely to provide climate refugia (Peterson *et al.* 2014), such as is present in western Oregon. The reserve land use allocations in the different alternatives and the Proposed RMP may provide some climate refugia, depending on location, size, orientation, and conditions on adjoining lands. Further, species migration rates typically lag behind climate velocity rates with considerable regional variation in both rates and direction (Dobrowski *et al.* 2013). Thus, while several studies indicate that climate velocity exceeds the migration rate of many plant species, including many tree species, determining the vulnerability of individual species to climate change based on climate velocity is difficult with large uncertainties.

As climate shifts, forest scientists expect background tree mortality will increase, but do not expect major die-offs of mature trees because of changing climate alone. Instead, die-offs are expected from the interaction between changing climate and disturbance events, such as drought and fire (Allen *et al.* 2010, Peterson *et al.* 2014) or the interaction between changing climate and increased competition for water and carbon (Clark *et al.* 2014). Changes in vegetation are likely to be abrupt following an event such as prolonged drought, insect outbreak, or wildfire, when mature trees are killed and regeneration fails. The bioclimatic envelope for seedlings of montane species, such as Douglas-fir and ponderosa pine, typically differs from and is narrower than the bioclimatic envelope in which established trees can persist (*Bell et al.* 2014). Species with broad distributions typically have ecotypes/climatypes adapted to local conditions; as local conditions change, a given climatype may not be able to reestablish following a disturbance. Using climate variables, Rehfeldt *et al.* (2014b, 2014c) predicted that the varieties of Douglas-fir and ponderosa pine found in western Oregon are likely to persist, although probably would not persist in an area that includes the Klamath Falls Field Office. In contrast, St Clair and Howe (2007), using characteristics such timing of bud set and bud break and root:shoot ratios, predicted that most coastal Douglas-fir ecotypes in western Oregon and Washington would be maladapted to the expected climate at the end of the 21st century. The authors posited that much of the risk arises from differences in drought hardiness in the different ecotypes relative to expected changes in seasonal and prolonged drought, and lengthening of the growing season (St Clair and Howe 2007). A more recent study found that Douglas-fir

[43] A climatype is a population defined primarily by the temperature and precipitation ranges to which it is presumably adapted genetically.

populations from areas with relatively cool winters and warm, dry summers, similar to that found in the Willamette Valley basin, might be better adapted to cope with future expected drought conditions than Douglas-fir from other areas (Bansal *et al.* 2015).

Available soil water during the growing season and soil water storage capacity are important drivers of which tree species can grow where and how well, particularly at lower and middle elevations (Chen et al. 2010, Weiskittel *et al.* 2011, Clark *et al.* 2014, Mathys *et al.* 2014, Peterson *et al.* 2014). Year-round soil water availability and evapotranspiration demand are primary factors in the distribution of western hemlock (Gavin and Hu 2006, Mathys *et al.* 2014). Western redcedar distribution is controlled in part by the availability of soil water in summer and winter (Mathys *et al.* 2014). Climate change is projected to extend growing seasons and increase evapotranspiration demand in summer, increasing the amount of drought stress forests in western Oregon will experience (Peterson *et al.* 2014). Site index for many species in western Oregon could decrease by 10–30 percent by 2060, largely due to increased dryness in the growing season (Weiskittel *et al.* 2011).

Potentially mediating the expected increased drought stress is the increasing atmospheric CO_2 concentrations. As atmospheric CO_2 concentrations increase, trees do not have to open stomates as frequently or for as long to obtain the amount of CO_2 necessary to drive photosynthesis, thereby reducing water loss that occurs at the same time (photorespiration) and increasing drought tolerance (Peterson *et al.* 2014). A recent study in the northern Rockies indicates that while both ponderosa pine and Douglas-fir have experienced increases in water use efficiency with increases in basal area increment in the latter half of the 20th century, ponderosa pine had greater increases, suggesting a possible shift in competitive advantage (Soulé and Knapp 2014). However, few studies have examined how different tree species might respond to changing atmospheric CO_2 concentrations, particularly in conjunction with changing temperatures.

Along with changing species composition is an expected decline in growth rates and overall site productivity, particularly under business as usual emissions scenarios (Shive *et al.* 2014, Diaz *et al.* 2015). Climate modeling indicates that such downward shifts would begin about mid-century with larger changes potentially occurring in the Coos Bay, Eugene, and Salem Districts, than in the Medford and Roseburg Districts and the Klamath Falls Field Office (Diaz *et al.* 2015). Using Climate-FVS Diaz *et al.* (2015) found that overall productivity could decline by one site class by mid-century and by two to three site classes by the end of the century as compared to current conditions, with the exception of the Klamath Falls Field Office. In the Klamath Falls Field Office area, productivity increased slightly by mid-century and then leveled out through the end of the century. These differences are likely due to how the different species and genotypes, and forests of different ages respond to drought and changing atmospheric CO_2 concentrations, particularly with respect to seedling establishment and survival (Anderson-Teixeira *et al.* 2013). The Coos Bay, Eugene, and Salem Districts have humid to subhumid climates whereas the Medford and Roseburg Districts and the Klamath Falls Field Office are semi-arid. Forests in humid climates respond primarily to short-term drought, in subhumid climates to both short- and long-term drought, and in semiarid climates to long-term drought (Vincente-Serrano *et al.* 2014). Thus, forests in the warmer, drier part of the planning area are less vulnerable to drought.

The changes in growth rates and site productivity have implications for timber production beyond mid-century. Under lower emissions scenarios that hold the rise in the average global temperature to less than 3.6 ºF, harvest volume can remain relatively unchanged, although total volume on the landscape declines and then levels out and management intensity may need to increase (Diaz *et al.* 2015). However, under business as usual emissions scenarios, maintaining a set harvest value is likely to result in the combination of harvest and tree mortality exceeding growth by the end of the century (Diaz *et al.* 2015). After mid-century, sustaining a particular yield of timber would likely require shorter rotations and more clearcutting with less thinning and uneven-aged management and would become increasing difficult as the variability in the harvestable volume available increases (Diaz *et al.* 2015). As the desired volume of stable harvest increases so does the difficulty in sustaining that volume become after mid-century under business as usual emissions scenarios, especially for the Coos Bay, Medford, and Roseburg Districts.

Insect Outbreaks and Pathogen Spread

Warming temperatures, wetter springs, and increased drought stress may increase the extent and impact from Swiss needle cast, sudden oak death, Port-Orford-cedar root disease, other root diseases such as Armillaria and Heterobasidion, bark beetles, and western spruce budworm in western Oregon (Chen *et al.* 2003, Manter *et al.* 2005, Campbell *et al.* 2006, Venette and Cohen 2006, Stone *et al.* 2008, Bentz *et al.* 2010, Chmura *et al.* 2011, Evangelista *et al.* 2011, Sturrock *et al.* 2011, Vose *et al.* 2012, Lee *et al.* 2013, Creeden *et al.* 2014, Flower *et al.* 2014, Peterson *et al.* 2014) (the discussion under Insects and Pathogens above has more detail). With their short generation times, both insects and pathogens can evolve more quickly than trees. Most insects and pathogens can migrate at faster rates than hosts, since wind and water disperse many of them farther than tree seeds (Sturrock *et al.* 2011, Peterson *et al.* 2014).

An additional effect may be the appearance of new insects and pathogens currently not present in western Oregon or the emergence of a minor insect or pathogen into a major disturbance factor (Bentz *et al.* 2010, Vose *et al.* 2012, Tillmann and Glick 2013, Peterson *et al.* 2014). Climate change will also alter biological synchrony between hosts and pests, since most pests are host-specific, but such changes and the resulting impacts are difficult to predict (Chmura *et al.* 2011, Sturrock *et al.* 2011). For example, both Douglas-fir bark beetle and spruce bark beetle have obligate adult dormancy periods (diapause) triggered by low temperature that could be disrupted by increasing minimum temperatures (Bentz *et al.* 2010).

Wildfire

A number of recent studies have examined the potential effects of climate change on wildfire, as well as what the potential changes in wildfire could mean to greenhouse gas emissions and carbon storage. Most studies have examined how annual burned area may change, while an increasing number of studies have begun examining how the probability of wildfire and wildfire severity may change. Using Climate-FVS Diaz *et al.* (2015) found that the area of high fire hazard would change very little under lower emissions scenarios and increase somewhat after mid-century under the business as usual emission scenario in the moister districts (Coos Bay, Eugene and Salem). In the warmer-drier portion of the decision area, the area of high fire hazard would increase somewhat under lower emissions scenarios but increase substantially and rapidly after mid-century under the business as usual scenario, particularly for the Medford and Roseburg Districts.

All studies examined indicate that the annual area burned would increase, although they differ on how much of an increase will occur, when, or where. Differing scales of analysis and analysis methods make direct comparisons between studies difficult. The National Research Council (2011) reported that for a 1 ºC increase in global temperature, burned area in the Cascades and Coast Range could increase by 428 percent and burned area in southwest Oregon could increase by 312 percent. Other estimates include a 78 percent increase in burned area by mid-century in the Pacific Northwest as a whole (Spracklen *et al.* 2009) and at least a 60 percent increase in western Oregon and Washington by the end of the century (Rogers *et al.* 2011). Warmer and drier conditions are the primary drivers behind these projected increases in burned area, as well as predictions of increased fire severity (Littell *et al.* 2009, Abatzoglou and Kolden 2013, Cansler and McKenzie 2013, Peterson *et al.* 2014). The wetter forests of western Oregon, mixed severity fire regimes, and high severity fire regimes are projected to see greater changes as warmer and drier conditions in summer and increased frequency of drought lengthen the fire season, the probability of severe fire weather increases, and the combination of drought and heating from fire adversely affect tree xylem conductivity (Hessl 2011, Rogers *et al.* 2011, Abatzoglou and Kolden 2013, van Mantgem *et al.* 2013, Peterson *et al.* 2014, Rogers *et al.* 2015). Rogers *et al.* (2015) attributed the increased vulnerability in the wetter forests to their inability to benefit from increased winter precipitation combined with the effects of increased summer drought. Under the Hadley climate model, increased fires in western Oregon would result in a predicted net loss of carbon by the end of the century (Rogers *et al.* 2015)

These same changes would also increase fire severity and the occurrence of very large fires (50,000 acres and larger) (Stavros *et al.* 2014b). Very large fires in the Pacific Northwest geographic area (Oregon and Washington) tend to occur under hotter, drier conditions, particularly in the first week following discovery of the fire, which historically occurred in three weeks (Stavros *et al.* 2014a, Stavros *et al.* 2014b). By mid-century, the number of weeks potentially supporting the occurrence of very large fires will increase to 6–8 weeks (Stavros *et al.* 2014b, supplementary table 1).

Other changes in wildfire include changes in fire probability and variability. Romps *et al.* (2014) projected a 50 percent increase in lightning occurrence across the continental U.S. by the end of the century. Guyette *et al.* (2014) predicted a 40–80 percent increase in fire frequency in western Oregon, with the largest changes predicted for colder and wetter ecosystems. Liu *et al.* (2013) also predicted increased inter-seasonal and inter-annual variability in fire potential along the Pacific coast. Using a process similar to one used in the Northwest Forest Plan 15-year monitoring report (Davis *et al.* 2011), Davis *et al.* (2014) projected that by 2060, the area where large wildfires are highly and very-highly probable would expand in the Klamath Falls Field Office, and the Medford and Roseburg Districts, and where large fires are at least moderately probable would expand into the Eugene, Salem, and Coos Bay Districts. However, the probability of large wildfires would remain low in most of the Coos Bay and Salem Districts.

Changes in annual area burned and fire severity would have clear implications for air quality, carbon storage potential, and greenhouse gas emissions as well. Greenhouse gas emissions would increase and carbon storage decrease as burned area and fire severity increase. Air quality typically degrades in years with higher acres burned and higher fire severity, due to longer duration burning on individual fires and greater degree of smoldering combustion that occurs during more severe fire seasons. This degradation typically results in more intrusions into mandatory Class I areas and greater effects to human health in Smoke Sensitive Receptor Areas (see Air Quality in this chapter). Earles *et al.* (2014) expect that as drought and fire frequency increase, carbon storage will destabilize where fire suppression has increased stand densities and ladder fuels and altered species compositions. The authors also assert that studies that compare the carbon effects of active management to no management in fire-suppressed forests are using the wrong baseline, based on a definition of carbon carrying capacity provided by Keith *et al.* (2009) (Earles *et al.* 2014). Keith *et al.* (2009) defined carbon carrying capacity in a manner that includes natural disturbance regimes, such as fire, but excludes anthropogenic disturbance, such as logging. Under this definition, as fire frequency and drought-induced mortality increases, carbon carrying capacity decreases with the implication that variability in carbon storage is much higher in fire-suppressed forests than in fire-included forests (Earles *et al.* 2014).

Scale mismatches means that important bottom-up controls on fire (e.g., topography, vegetation, and fuel availability) cannot be adequately incorporated into projections of how climate change may affect wildfires (Cansler and McKenzie 2013, Bowman *et al.* 2014). Other sources of uncertainty include whether drought-induced tree mortality will increase and tree responses to increased atmospheric CO_2 concentrations (Hurteau *et al.* 2014). Predictions of changes in burned area, fire size, and fire severity assume that past relationships between climate and fire continue to hold (Littell *et al.* 2009, Cansler and McKenzie 2013, Bowman *et al.* 2014). If past relationships between climate and fire do not hold, it is not clear what would change, how, or when. If they do hold, then the landscapes of the future are likely to have a higher proportion in homogeneous, early seral patches, lower biodiversity, and lower resilience to other stressors, primarily in drier forests (Cansler and McKenzie 2013, Peterson *et al.* 2014). Climate and weather are top-down controls on fire (e.g., Littell *et al*. 2009, Abatzoglou and Kolden 2013, and Higuera *et al*. 2015), but bottom-up controls are also important (e.g., Halofsky *et al*. 2011, Bowman *et al*. 2014, Peterson *et al*. 2014, and Higuera *et al*. 2015); the greater the spatial complexity of bottom-up controls, the less likely that top-down controls will override them (Cansler and McKenzie 2013).

Streamflow and Temperature

By mid-century, climate modeling indicates peak flows from snowmelt would occur 3–4 weeks earlier in the Pacific Northwest as compared to the current timing (Dalton *et al.* 2013 and references therein). All streams in western Oregon would be rain-dominant by the end of the century (Dalton *et al.* 2013 and references therein, Figure 3.2; Klos *et al.* 2014). Since rain-dominant streams tend to experience peak flows earlier than snow-dominant systems, some streams originating in the Cascades would experience earlier peak flows and reduced spring and summer flows (Dalton *et al.* 2013). If winter precipitation increases as projected, peak flows would increase in magnitude, but timing would otherwise not change in systems that are already rain-dominated (Dalton *et al.* 2013). Mean annual streamflow could initially decrease by the 2020s, possibly due to increased evapotranspirational demand, and then increase through the end of the century by 0.6 to 5.5 percent, apparently driven by projected increases in winter precipitation (Wu *et al.* 2012). Mean summer streamflow is expected to continually decrease, becoming approximately 30 percent less by the end of the century (Wu *et al.* 2012)

Non-climate factors, such as degree of stream shading, amount of groundwater input, and how streams and reservoirs are managed are also important drivers of stream temperatures, and can result in stream cooling at the same time that air temperatures are warming (Arismendi *et al.* 2012). Regardless, in the Northwest, warming air temperatures and declining summer base flows are strongly associated with warming stream temperatures (Kaushal *et al.* 2010, Isaak *et al.* 2012), with additional warming expected through the 21st century. If past trends continue, then some streams would be 1.6–2.0 ºF warmer by mid-century than the 1980– 2009 baseline (Isaak *et al.* 2012, Wu *et al.* 2012).

Wildlife and Wildlife Habitat

Very few studies have examined the potential implications of climate change for northern spotted owls, and the BLM found no studies that directly addressed marbled murrelet. Rapid climate change could place additional stress on species already at risk of extinction from habitat loss, such as Fender's blue butterfly (Hixon *et al.* 2010). Fish and wildlife species considered most vulnerable to climate change include—

- Several terrestrial and many aquatic invertebrates;
- Amphibians and cold-water fish, especially those with restricted ranges or narrow temperature requirements;
- Long-distance migratory shorebirds that winter or stop over in western Oregon; and
- Forest birds, especially those associated with either early seral habitat or old-growth habitat (Hixon *et al.* 2010 and references therein, NABCI 2014).

Projecting climate change effects on most terrestrial species is limited by the current inability of vegetation models to project changes in stand structure in response to climate changes, and the lack of knowledge of how climate directly influences the presence, absence, and fecundity of a given species (Carroll 2010, Hixon *et al.* 2010). Carroll (2010) projected that the extent of suitable habitat for northern spotted owl could contract in the Coast Range and southwest Oregon and shift upward in elevation in the Cascades by the end of the century, primarily due to changes in precipitation regimes that affect survival (see also Franklin *et al.* 2000, Glenn *et al.* 2010, Glenn *et al.* 2011).

Changes in disturbance regimes could disfavor species associated with old-growth forests, by shifting more of the landscape into earlier seral stages, altering species compositions to ones less preferred, reducing the extent of large trees and structurally-complex forest, and decreasing patch sizes preferred for different life stages, such as nesting (Vose *et al.* 2012, Dalton *et al.* 2013, section 5.4.2, Peterson *et al.* 2014). These same types of changes could also adversely affect preferred prey species for predators like the northern spotted owl, although the ability of the owl to shift prey preferences is not well documented. Ocean warming and changes in ocean chemistry along with increasing extent and duration of dead zones (Hixon *et al.* 2010, Section 7.4 and references therein, Dalton *et al.* 2013, Chapter 4) could adversely affect the prey base used by species such as marbled murrelet.

Potential Effects of Alternatives in Adapting to Climate Change

In general, BLM actions to respond to changes in climate (such as modifying seed stock for replanting after harvest) would be implementation-level decisions that would be made subsequent to the approval of the RMP. This discussion considers how the alternatives and the Proposed RMP would set the stage for the BLM to take such actions in the future.

The current Douglas-fir-western hemlock-western redcedar forests typical of western Oregon developed in the last 5,600 years, apparently in response to cooling climate (Shafer *et al.* 2010 and references therein, p. 178). Historical tree migration rates during the Holocene range from 6 to 93 miles per century, whereas the current climate velocity is estimated at 186–311 miles per century (Tillmann and Glick 2013 and references therein, p. 200). Given the expected climate velocity and the potential changes discussed above, scientists who study climate change impacts on natural resources recommend varying levels of active management in order to preserve or protect social and ecosystem values (e.g., Joyce *et al.* 2009, Spies *et al.* 2010, Peterson *et al.* 2011, Stein *et al.* 2014, and Millar and Stephenson 2015). Stein *et al.* (2014) classify potential management actions into three general categories:

1. Resistance actions – those intended to maintain the status quo of species and systems
2. Resilience actions – those intended to improve the capacity of the system to return to desired conditions or to maintain some level of desired functionality in an altered state
3. Realignment actions – those intended to enable or facilitate the transition to a new functional state

However, many of the recommended types of forest management actions tend to overlap at least two of the categories. Generally, recommended actions for responding to climate change consist of reducing existing stresses, increasing resistance and resilience to climate change and other stressors, and enabling change where it is inevitable (Joyce *et al.* 2009, Spies *et al.* 2010, Peterson *et al.* 2011, Vose *et al.* 2012, Peterson *et al.* 2014, Stein *et al.* 2014). As summarized by Joyce *et al.* (2009), Spies *et al.* (2010), and Peterson *et al.* (2011) specific types of recommended actions include—

- Thinning forest stands to reduce competition and drought stress, increase diversity (species, structure, age classes, sizes, patch sizes, spacing) at the stand and landscape scales, and increase resistance to fire, insects, and pathogens;
- Protecting large old trees, large snags, and large downed wood;
- Planting new genotypes/ecotypes/climatypes and species to aid development of communities that can persist under both the current and expected future climate; and
- Identifying potential climate change refugia at regional and local scales

These approaches are known as ‘no regrets’ decisions and bet-hedging, given the large uncertainties over the rate and magnitude of climate change in any one location (Vose *et al.* 2012).

Whether thinning would increase or reduce forest resiliency in the face of climate change is scientifically controversial. Studies have shown strong evidence that unmanaged forests have great capacity for so-called self-correction and self-organization following natural disturbances (e.g., Peterson 2002, Scholl and Taylor 2010, and Amoroso *et al*. 2013) and some types of harvest prescriptions (e.g., Drever *et al*.

2006 and Messier *et al.* 2015). Of particular concern is misapplying thinning prescriptions more suitable for low-severity fire regimes to mixed-severity fire regimes (e.g., Odion *et al.* 2014 and DellaSala *et al.* 2015). In part, the controversy is about the breakpoint between low and mixed severity. The severity of any particular disturbance occurs on a continuum which scientists and managers bin into categories usually labeled as low, mixed, and high severity. Since there is no scientific method for determining breakpoints along a continuum, the definition of severity categories is subjective. While the scientific community has long recognized that the low-severity bin includes some amount of high severity patches, scientists disagree on how much high severity can be present before the appropriate bin should be mixed severity. The BLM uses the fire severity classes developed under the LANDFIRE project; which defines low severity as 6–25 percent stand replacement (high severity patches) (NIFTT 2010, p. 99). Others believe that low severity regimes contain less than 25 percent stand replacement (e.g., Odion *et al.* 2014 and Hanson *et al.* 2015). This differing view creates disagreement on what parts of the landscape fall into the different fire regimes and, therefore, what thinning prescriptions are appropriate. In addition, climate change will result in shifting the locations of the different fire regimes, but no one can say with much accuracy or precision when, where, and how rapidly these shifts may occur. Shifts are more likely to manifest after a stand replacement disturbance occurs and the site is no longer capable of returning to a condition similar to the past. One concern is that more intense thinning might trigger a similar outcome through the combined effects of reducing stand density and shading, shifting species composition, and the associated impacts of logging operations.

Within the scientific community, the use of assisted, or facilitated, migration as a climate change adaptation technique is controversial. Assisted migration consists of the deliberate movement of species or ecotypes into locations where they presently do not occur instead of waiting for natural migration into these locations. Hewitt *et al.* (2011) provides the most recent paper summarizing the nature of the scientific debate. Sixty percent of the papers the authors examined were supportive of assisted migration, 20 percent opposed, and 20 percent did not have a clear position. Arguments in favor of assisted migration include climatically suitable ranges outpacing migration rates, the risks of adverse outcomes are manageable with decision tools, the need for proactive measures to prevent biodiversity losses and extinctions, and the lack of appropriate or sufficient migration corridors. Arguments against assisted migration include risks of a species becoming invasive, costs, uncertainties over outcomes, the risk of legitimizing unauthorized and unregulated introductions, diversion of resources from higher conservation priorities, and bias toward species humans or societies deem important. Invasion risks are a particularly common argument against assisted migration, but seem to have the most relevance with respect to introducing completely new species or transferring species between continents (Vitt *et al.* 2010, Hewitt *et al.* 2011 and references therein, Winder *et al.* 2011). Moving different genotypes of species within its current range or assisting in relatively short-distance range expansions appears to be much less controversial, although these moves are not risk-free either (Aitken *et al.* 2008, Vitt *et al.* 2010, Hewitt *et al.* 2011, Winder *et al.* 2011). Some studies identified assisted migration as a primary need in order to preserve the presence of a forest, although not necessarily the present type of forest, in the face of climate change and associated changes in disturbance risks (Woods *et al.* 2010, Buma and Wessman 2013).

Management to adapt to climate change may not necessarily be consistent with management to maximize carbon storage. D'Amato *et al.* (2011) caution that rigid adherence to a single objective, such as maximizing carbon storage, is likely to result in adverse effects to other ecosystem components critical to long-term functioning in the face of changing climate. Increased burned area from wildfires in the mesic maritime forests of the Pacific Northwest could result in loss of up 1,900 Tg of carbon by the end of the century, an amount equal to 23 times the current combined emissions from all sources in Oregon and Washington (Rogers *et al.* 2011). Many studies have found that active management, particularly in forests adversely affected by fire suppression, could reduce both carbon losses and increases in greenhouse gas emissions from wildfires. Results from various thinning and burning prescriptions indicate that the short-term reductions in carbon result in long-term benefits to carbon storage and greenhouse gas emissions by reducing fire-induced mortality, maintaining a higher fraction of carbon in live trees, increasing drought resistance, and reducing competition for water, nutrients, and light (Stephens *et al.* 2009, Hurteau and North 2010, North and Hurteau 2011, Stephens *et al.* 2012, Bowman *et al.* 2013, Hurteau *et al.* 2014, Loudermilk *et al.* 2014, Volkova *et al.* 2014). Other studies indicate that such potential benefits are unlikely to occur in moister forests with longer fire return intervals (e.g., Mitchell *et al*. 2009, Campbell *et al.* 2011, McKinley *et al.* 2011, Bowman *et al.* 2013, and Keith *et al.* 2014).

The degree to which an alternative or the Proposed RMP promotes active management provides opportunities to adapt to changing climate. In dry forests under all action alternatives and the Proposed RMP, management would emphasize increasing fire resistance and resilience, which would often also increase resistance to drought, insects, and pathogens. The No Action alternative does not explicitly prohibit management to increase fire resistance and resilience, but does not have the same emphasis as in the action alternatives and the Proposed RMP, especially within the Late-Successional Reserve and the Riparian Reserve allocations. This uncertainty in the management direction of the No Action alternative adds uncertainty to the implementation of actions to increase fire resistance and resilience, especially within reserve land use allocations in the dry forest.

Retaining portions of stands through uneven-aged management would reduce risks associated with reforestation failure in dry forests. All action alternatives and the Proposed RMP would manage the Harvest Land Base in the driest forests with uneven-aged management. In contrast, the No Action alternative would include regeneration harvest throughout the Harvest Land Base in the driest forests, increasing the risk of reforestation failure.

Reforestation after timber harvest or disturbance would provide opportunities to shift tree species composition or genotypes/ecotypes/climatypes under all alternatives and the Proposed RMP, except Alternative B in the Light Intensity Timber Area, where the BLM would use only natural regeneration. In addition to the risk of reforestation failures, the inability to replant after timber harvest or disturbance in this portion of the Harvest Land Base under Alternative B would limit the ability to adapt to climate change through replanting (see the Forest Management section in this chapter).

Reserves with minimal or no active management may provide areas of greater ecological stability on the landscape and provide benchmarks for comparison with actively managed areas. However, it is unclear to what extent such minimally managed reserves would be more stable and more resistant to climate change effects. As discussed under the previous subsection on tree species, major shifts in plant communities are expected to be abrupt arising from the interaction of climate change and another disturbance (Paine *et al*. 1998, Allen *et al.* 2010, Lindenmayer *et al*. 2011, Peterson *et al.* 2014, Clark *et al.* 2014). These shifts can lead to new plant communities and ecosystems not previously seen within the planning area (Paine *et al*. 1998, Lindenmayer *et al*. 2011, Peterson *et al*. 2014). This disturbance could be forest management, one or more natural events, such as wildfire or insect outbreak, or both in combination. The combination of forest management and natural events could trigger development of so-called novel plant communities in the actively managed areas, whereas in minimally managed areas, the trigger would more likely be one or more natural events. Comparing recent satellite imagery of western Oregon with that collected in the mid-1990s, reserves with minimal or no active management tended to become homogeneous with respect to stand density, age, and condition. Such landscapes appear to be increasingly vulnerable to large, stand-replacing fire and the development of large, stand-replacing patch sizes based on recent fires and maps of burn severity. Shive *et al.* (2014) found that treating stands before a wildfire could be critical to retaining desired tree species in the face of climate change and the presence of wildfire even if at lower stand densities or basal area than in the past. Fire, insects, and pathogens often interact such that the occurrence of one of these disturbance types facilitates the occurrence of another (Vose *et al.* 2012, Tillmann and Glick 2013, Peterson *et al.* 2014). The larger the area in Reserves with minimal management, the more limited BLM's management options would be to adapt to climate change over time.

In contrast to the risks of minimal management, areas with minimal vegetation management may provide refugia against climate change. Within the decision area, minimal vegetation management would occur in Congressional Reserves such as designated Wilderness and some Wild and Scenic River corridors, certain other reserves, such as some ACECs and Wilderness Study Areas, District-Designated Reserve – Lands Managed for their Wilderness Characteristics, portions of the Late-Successional Reserve that are structurally-complex forest or occupied marbled murrelet sites, and the inner zone of the Riparian Reserve under the action alternatives and the Proposed RMP. Climate change refugia provide conditions where species either may retreat or persist during long-term climatic change (e.g., Keppel *et al*. 2015, Olson *et al*. 2012, Gillson *et al*. 2013, and Buttrick *et al*. 2015). Species with narrow distributions or specialized habitat requirements that greatly constrain the ability to migrate to new locations are most vulnerable to climate change (Damschen *et al*. 2010, and Keppel and Wardell-Johnson 2012). In the absence of refugia, such species are more likely to face local extirpation or general extinction (e.g., Damschen *et al*. 2010). Climate refugia are more likely to occur in complex terrain where landform, topographic shading, and cool air drainage can moderate expected increases in temperature, thus maintaining habitat stability and climatic stability or slowing the rate of change (Ashcroft 2010, Spies *et al*. 2010, Buttrick *et al*. 2015). Climate refugia can occur at more than one scale, usually referred to as macrorefugia and microrefugia, but need to be large enough to support a small population of the species of interest (Ashcroft 2010). The BLM's predominately checkerboard land ownership pattern limits the opportunity to provide macrorefugia. The Late-Successional Reserve network may provide climate change macrorefugia for species that are also able to disperse around or through the intervening lands, most of which are managed for timber production. In contrast, designated Wilderness, Wilderness Study Areas, some ACECs, and District-Designated Reserve – Lands Managed for their Wilderness Characteristics and the inner zone of the Riparian Reserve in the action alternatives and the Proposed RMP, are likely to provide climate change microrefugia in some locations. Buttrick *et al*. (2015) identified much of western Oregon as having moderate to high terrestrial resilience to climate change (defined as likely to retain and support higher biodiversity as climate changes), although much of the lower elevations, where most BLM-administered lands occur in the planning area, range from below average to above average resilience.

The size of the inner zone of the Riparian Reserve provides the main difference among the alternatives and the Proposed RMP for climate change microrefugia. Alternative D, with the widest inner zone on all stream types, would provide the largest amount of potential climate change microrefugia, followed by Alternative A. The Proposed RMP would the same size inner zone along fish-bearing and perennial streams as Alternatives A and D, and would provide wider inner zones along intermittent and non-fish-bearing streams than Alternatives B and C in most watersheds. See also the discussion in the Hydrology section of this chapter under Issue 1 concerning effective stream shading as an indicator of potential climate microrefugia.

The ability of active management to mitigate projected changes in stream temperature appear to be limited since changing air temperatures account for much of the expected changes in stream temperature (Holsinger *et al.* 2014). Equally important, however, is that wildfires and fuels management appear to have limited ability to adversely affect stream temperatures much beyond the immediate affected area. The inner zone of the Riparian Reserve in the action alternatives and the Proposed RMP would provide some degree of mitigation for climate change, but the degree of that mitigation depends on landform, degree of topographic shading, degree of cool air drainage from higher elevations, and primary water source (e.g., surface water from rain versus ground water recharged from snowpacks). Checkerboard ownership patterns limit the ability of management direction on the BLM-administered lands to help reduce the magnitude or rate of stream temperature rise as streams cross through younger forests with shorter rotations.

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