Northwest

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The state of knowledge about climatic effects on forests of the Northwest region was recently summarized in a peer-reviewed assessment of these effects in Washington (Littell et al. 2009, 2010) and a white paper on climatic effects on Oregon vegetation (Schafer et al. 2010). Recent PNW and West-wide modeling studies provide additional scenarios for effects of climate change on wildfire, insects, and dynamic vegetation in Oregon and Washington. This summary describes evidence for such effects on climate-sensitive forest species and vegetation distribution, fire, insect outbreaks, and tree growth.

Based on projections of direct effects of climate change on the distribution of Northwest tree species and forest biomes, widespread changes in equilibrium vegetation are expected. Statistical models of tree species-climate relationships (e.g., McKenzie et al. 2003) show that each tree species has a unique relationship with limiting climatic factors (McKenney et al. 2011; McKenzie et al. 2003; Rehfeldt et al. 2006, 2008). These relationships have been used to project future climate suitability for species in western North America (McKenney et al. 2007, 2011; Rehfeldt et al. 2006, 2009) and in Washington in particular (e.g., Littell et al. 2010 after Rehfeldt et al. 2006). Climate is projected to become unfavorable for Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) over 32 percent of its current range in Washington, and up to 85 percent of the range of some pine species may be outside the current climatically suitable range (Littell et al. 2010, Rehfeldt 2006). Based on preliminary projections from the global climate model (GCM) CCSM2 and the process model 3PG, Coops and Waring (2010) projected that the range of lodgepole pine (*Pinus contorta* var. *latifolia* Engelm. ex S. Watson) will decrease in the Northwest. Using similar methods, Coops and Waring (2011) projected a decline in current climatically suitable area for 15 tree species in the Northwest by the 2080s; five of these species would lose less than 20 percent of this range, and the range of the other 10 species would decline up to 70 percent.

Various modeling studies project significant changes in species distribution in the Northwest, but with considerable variation within and between those studies. McKenney et al. (2011) summarized responses of tree species to climate change across western North America for three emissions scenarios. Projected changes in suitable climates for Northwest tree species ranged from near balanced (-5 to +10) to greatly altered species distribution at the subregional scale (-21 to -38 species), depending on the emissions scenario. Modeling results by Shafer et al. (2010) indicate either relatively little change over the 21st century under a moderate warming, wetter climate (CSIRO Mk3, B1), or, in western Oregon, a nearly complete conversion from maritime to evergreen needleleaf forest and subtropical mixed forest under a warmer, drier climate (HadCM3, A2). Lenihan et al. (2008) concluded that shrublands would be converted to woodlands, and woodlands to forest in response to elevated carbon dioxide, a trend that would be facilitated by fire suppression.

Potential changes in fire regimes and area burned have major implications for ecosystem function, resource values in the wildland-urban interface, and expenditures and policy for fire suppression and fuels management. The projected effects of climate change on fire in the Northwest generally suggest increases in both fire area burned and biomass consumed in forests (Littell et al. 2009, 2010; McKenzie et al. 2004). Littell et al. (2010) used statistical climate-fire models to project future area burned for the combined area of Idaho, Montana, Oregon, and Washington. Median regional area burned per year is projected to increase from the current 0.2 million ha, to 0.3 million ha in the 2020s, 0.5 million ha in the 2040s, and 0.8 million ha in the 2080s. Furthermore, the area burned compared to the period 1980 through 2006 is expected to increase, on average, by a factor of 3.8 in forested ecosystems (western and eastern Cascades, Okanogan Highlands, Blue Mountains). Rogers et al. (2011) used the MC1 dynamic vegetation model to project fire area burned, given climate and dynamic vegetation under three GCMs. Compared to 1971 to 2000, large increases are predicted by

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2100 in both area burned (76 to 310 percent, depending on climate and fire suppression scenario) and burn severities (29 to 41 percent).

Tree vigor and insect populations are both affected by temperature: host trees can be more vulnerable because of water deficit, and bark beetle outbreaks are correlated with high temperature (Powell and Logan 2005) and low precipitation (Berg et al. 2006). Littell et al. (2010) projected relationships between climate (vapor pressure deficit) and mountain pine beetle (*Dendroctonous ponderosae* Hopkins) (MPB) attack in the late 21st century. They also projected potential changes in MPB adaptive seasonality, which suggested that the region of climatic suitability will move higher in elevation, eventually reducing the total area of suitability. Using future temperature scenarios for the PNW, Bentz et al. (2010) simulated changes in adaptive seasonality for MPB and single-year offspring survival for spruce bark beetle (*Dendroctonus rufipennis* Kirby) (SBB). The probability of MPB adaptive seasonality increases in higher elevation areas, particularly in the southern and central Cascade Range for the early 21st century and in the north Cascades and central Idaho for the late 21st century. Single-year development of SBB offspring also increases at high elevations across the region in both the early and late 21st century.

Response of tree growth to climate change will depend on subregional-to-local characteristics that change the sensitivity of species along the climatic gradients of their ranges (e.g., Chen et al. 2009, Littell et al 2008, Peterson and Peterson 2001). Douglas-fir is expected to grow more slowly in much of the drier part of its range (Chen et al. 2009) but may currently be growing faster in many locations in the Northwest (Littell et al. 2008). Although no regional synthesis of expected trends in tree growth exists, the projected trend toward warmer and possibly drier summers in the Northwest (Mote and Salathé 2010) is likely to increase growth where trees are energy limited (at higher elevations) and decrease growth where trees are water limited (at lowest elevations and in driest areas) (Case and Peterson 2005, Holman and Peterson 2006, Littell et al. 2008). Growth at middle elevations will depend on summer precipitation (Littell et al. 2008).

The effects of climate change on forest processes in the Northwest are expected to be diverse, because the mountainous landscape of the region is complex, and species distribution and growth can differ at small spatial scales. Forest cover will change faster via disturbance and subsequent regeneration over decades, rather than via gradual readjustment of vegetation to a new climate over a century or more. Additional data are needed on interactions between disturbances and on connections between climate-induced changes in forests and ecosystem services, including water supply and quality, air quality, and wildlife habitat. In addition, projected changes in forest distribution, structure, and function need to be synthesized using recent GCM projections, including quantification of uncertainties about the effects of climate on forest processes.

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