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RESEARCH ARTICLE

Climate change adaptation strategies for federal forests of the Pacific Northwest, USA: ecological, policy, and socio-economic perspectives

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Abstract Conserving biological diversity in a changing climate poses major challenges for land managers and society. Effective adaptive strategies for dealing with climate change require a socio-ecological systems perspective. We highlight some of the projected ecological responses to climate change in the Pacific Northwest, U.S.A and identify possible adaptive actions that federal forest managers could take. The forest landscape, ownership patterns and recent shift toward ecologically based forest management provide a good starting place for conserving biological diversity under climate change. Nevertheless, undesirable changes in species and ecosystems will occur and a number of adaptive actions could be undertaken to lessen the effects of climate change on forest ecosystems. These include: manipulation of stand and landscape structure to increase ecological resistance and resilience; movement of species and genotypes; and engaging in regional, multi-ownership planning to make adaptive actions more effective. Although the language and goals of environmental laws and policies were developed under the assumption of stable climate and disturbance regimes, they appear to be flexible enough to accommodate many adaptive actions. It is less certain, however, if sufficient social license and economic capacity exist to undertake these actions. Given the history of contentious and litigious debate about federal forest management in this region, it is likely that some of these actions will be seen as double-edge swords, spurring social resistance, especially where actions involve cutting trees. Given uncertainties and complexity, collaborative efforts that promote learning (e.g. adaptive management groups) must be rejuvenated and expanded.

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Introduction

The Pacific Northwest (PNW) region of the U.S. (Fig. 1) has been both active and influential in the development and implementation of scientifically-based forest

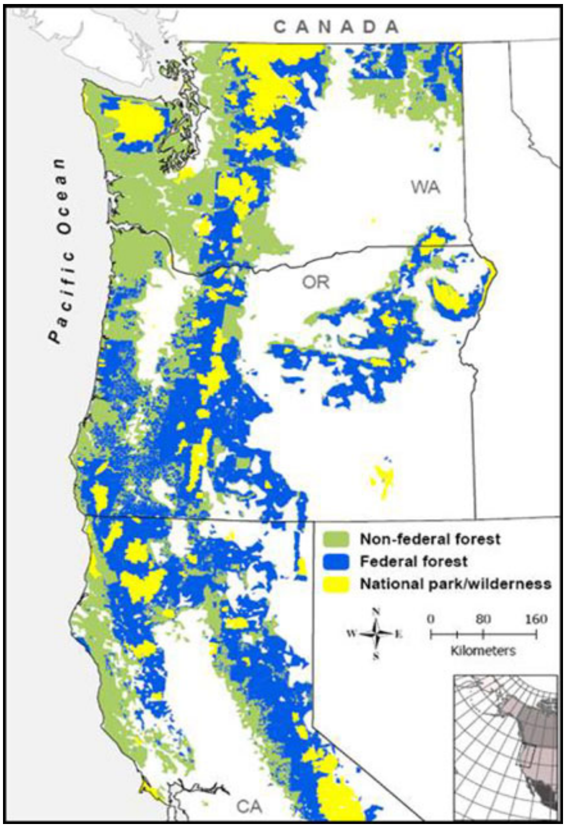

Fig. 1 Pacific Northwest region showing forest land and major ownership classes

biodiversity laws, policies and practices especially for public lands. Over the last 20 years several large scientific assessments have been conducted to evaluate the status of biodiversity and ecosystem services and new forest management policies and plans have been implemented on various ownerships (Johnson et al. 1999; Spies et al. 2007). These policies were intended to produce specific biodiversity outcomes in terms of species populations, habitats, and stand and landscape vegetation conditions (e.g. old-growth forests). Although the recent plans were intended to be long-term and adaptive, it is not clear how successful they will be under climate change and how adaptive they can be in a dynamic biophysical and social environment characterized by high levels of uncertainty and mistrust of public land managers by some segments of society. In fact, the success of these policies is already challenged by large wildfires that have converted thousands of hectares of old-growth forests into early successional vegetation, and the spread of competitor species and diseases that threaten species conservation of at-risk plant and animal species (Lint 2005; Schwandt 2006).

It is important to know the potential of existing policies for conserving biodiversity under climate change, given that these policies generally assume stable climates, disturbance regimes, and biotic interactions. There are many reasons to be concerned that our forests are at risk and that our forest policies and practices may not be well designed to deal with climate change. For example, management for timber production in the 20th century (first on private lands and later on federal lands) was devoted largely to converting ecologically diverse native forests to intensively managed plantations composed of a few native commercial tree species. Such areas of relatively young, uniform forests may be at higher risk to wildfire, insects, and disease than older and more ecologically diverse forests.

Dry, fire-prone forests in many areas are now filled with live and dead fuels as a result of fire suppression and the absence of fire through much of the 20th century. The policies of the 1990s that were designed to protect old-growth forests, northern spotted owls (NSO) (*Strix occidentalis*), and salmonids did not explicitly consider climate change. Only one recent study has evaluated the effectiveness of the current reserve network under climate change in the Pacific Northwest (Carroll et al. 2009).

Forest managers' potential responses to ongoing climate change include mitigation and adaptation (Millar et al. 2007). Mitigation of global climate change is typically associated with activities that reduce carbon emissions. Adaptive actions are intended to facilitate species and ecosystem adjustments to climate change. Potential adaptive actions include reducing fuels to lower the risk of loss to high severity fire (Noss et al. 2006), maintaining or increasing connectivity to facilitate species migration, and moving genotypes and species to promote establishment of populations that are adapted to local environments under rapid climate change (Aitken et al. 2008). While a scientific consensus is emerging on the range of possible impacts and human responses to climate change, specific responses in particular regions and landscapes are not yet understood and the relative importance of mitigation versus adaptation is still hotly debated (Orr 2009).

In this paper we examine these challenges in terms of actions that might enhance the capacity of species and forests of the PNW region to adapt to the climatic changes that are expected over the next 30 or so years—a period over which rates of change in temperature are forecast to be relatively stable and no trends in annual precipitation are expected (Salathé et al. 2008). However, biological and ecological responses to these changes will play out well beyond 30 years, especially if rates of climate change accelerate in the latter half of the 21st century. We argue that recent ecologically-based policies provide a solid foundation for developing adaptation strategies, but future management responses to climate change require flexibility and an approach that considers the ecological, economic, regulatory, and social dimensions of the issue. We focus primarily on federal lands, but we provide regional context in terms of all lands. Our objectives are to (1) review possible climate changes and their ecological effects; (2) identify potential adaptive actions; (3) examine how policies and socio-economic forces may constrain adaptive actions; and (4) suggest ways that adaptive management could be reinvigorated to deal with climate change.

The setting

The Pacific Northwest is a mountainous region dominated by strong west-east moisture and temperature gradients associated with interactions among marine and continental air masses and mountainous topography (Fig. 1). The climate is characterized as Mediterranean with wet, cool winters and warm, dry summers. Annual precipitation ranges from over 3000 mm at high elevations in coastal mountains to less than 300 mm in high plateaus in the interior (eastern) parts of the region.

Forest vegetation is dominated by coniferous species and plant community patterns are strongly associated with climate (Franklin and Dyrness 1988; Ohmann and Spies 1998). Forests are highly productive at low to mid elevations west of the crest of the Cascade Range and have relatively low productivity on the dry east side (Franklin and Dyrness 1988). The natural disturbance regimes are dominated by mixed- to high-severity fires, with insects and disease and low-severity fire becoming more important on the drier, low productivity sites (Agee 1993). Stand replacement fire return intervals in the coastal areas range from about 80 to over 500 years, with many areas ranging between 200 and 400 years. In interior areas fires are more frequent (10–50+ years) and less severe than in coastal areas. Over the last 60–90 years fire suppression and climate variation have contributed to accumulation of understory fuels in the dry forests increasing the probability of high severity fire. Fuel accumulations have not been an issue in wetter forests, where wildfire has been more weather limited.

The pattern of ownership of PNW forest lands has a strong influence on forest structure and biodiversity potential (Spies et al. 2007). About 50% of the forest of the region is federally owned, with the remainder in the hands of a mix of state, industrial private, and non-industrial private owners (Fig. 1). The management of the federal lands has changed much over the last 60 years. It began with a stewardship period in the early 20th century that gave way to a multiple-use period (~1950s–1980s) that was dominated by timber production.

Since the 1990s management of federal forests has emphasized ecological goals. The recent changes have been embodied in a series of policies starting with the Wilderness Act (1964) (TWA), National Environmental Policy Act (1969) (NEPA), Endangered Species Act (1973) (ESA), National Forest Management Act (1976) (NFMA), and the Northwest Forest Plan (1994) (NWFP). Policies for state-owned lands and private forest lands have shifted toward recognizing ecological and biodiversity values but timber management is still the primary goal, and the most dramatic shifts in management have been on the federal lands (Spies et al. 2007).

Climate change projections

Global climate change simulations and regional climate models for the PNW forecast warming trends across the region with variable trends in precipitation (Zhang et al. 2007; Salathé et al. 2008) over the next 30 or so years. These could generally increase summer moisture deficits and produce longer and more intense summer dry periods. Climate changes will not be uniform across this region. For example, regional-level models indicate that warming will be

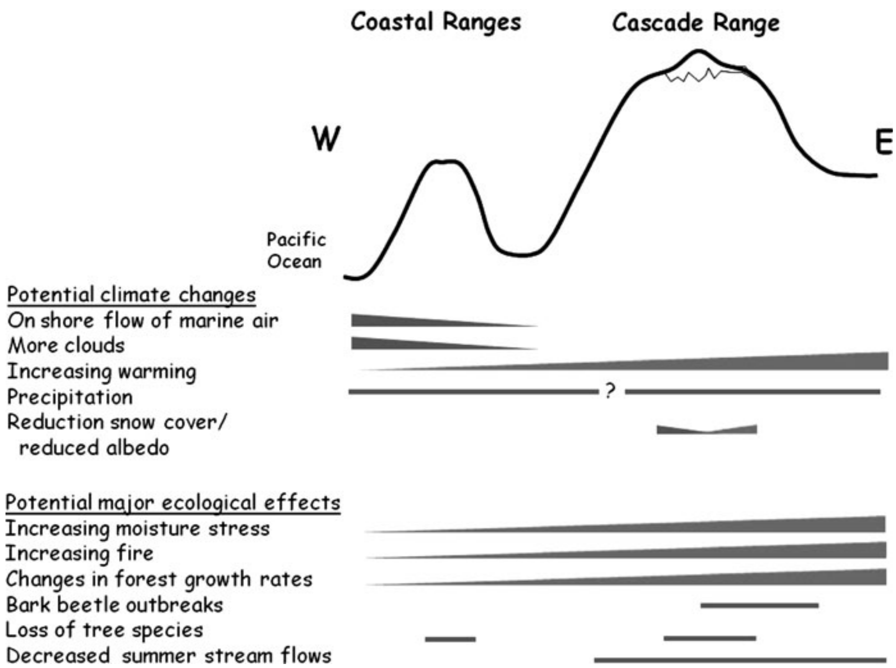

Fig. 2 Generalized examples of potential climate changes that are projected for the next 30 years and possible ecological responses (which will play out over decades to centuries) along a gradient from the coast to the interior for the central part of the Pacific Northwest Region. Thicker parts of bars indicate relatively stronger changes or responses

most pronounced away from coastal mountains, at high elevation, and in the interior (Fig. 2) (Salathé et al. 2008). Precipitation, however, shows no consistent trend across the region over the next 30 years. Interactions among snow cover, albedo, cloudiness, circulation patterns, and regional topography may lead to complex regional scale patterns in temperature (Salathé et al. 2008). For example, in mountainous areas away from the coast where snow cover is lost because of warmer winters and earlier springs, a snow-albedo feedback process is likely to amplify warming. Increased onshore flow of ocean air may limit warming in coastal areas and increase cloud cover over the western portion of the region (Salathé et al. 2008).

Studies at landscape scales (e.g. 10^3–10^5 ha) indicate that the topographic influences on warming patterns may be expressed at finer scales as well. For example, Daly et al. (2009) (Fig. 2) found that cold air drainage and pooling in mountainous terrain could dampen warming in these environments, while higher topographic positions that are more closely coupled to synoptic weather systems might experience elevated warming.

Climate modeling offers our best guess at future climatic conditions, and regional modeling, with finer spatial resolution, could be better than global modeling at reflecting local features such as complex and pronounced topography. Vegetation responses to regional climate will be mediated by local variation in topography and soil and these finer scale environmental controls may limit global and large regional climatic effects (Randin et al. 2009). For example, current climate models do not reflect fine-scale (e.g., <15 km $\times$ 15 km) complex topography. However, regional models contain all the uncertainties of the global climate model(s) (Sheperd et al. 2009) and accurate regional PNW climate models are not likely to become available anytime soon. This uncertainty is a fact of life for climate models and should not be taken as reason for not responding to climate change (Wiens et al. 2009).

Possible ecological impacts

Climate change will alter ecosystems and biodiversity, but the effects will be variable and characterized by a high level of uncertainty. Responses will also be manifest over a century or more because of lags in biological processes such as mortality, regeneration, dispersal, and fine-scale environmental heterogeneity, which could dampen effects of regional-scale climatic change (Randin et al. 2009). Climate change effects on forests can be classified as direct (e.g. effects on ecophysiology and population dynamics of organisms and hydrological processes) and indirect (effects on disturbance regimes that then affect species and ecosystems) (Franklin et al. 1992; McKenzie et al. 2004). Specific responses to climate change are likely to include: (1) changes in growth, vigor and reproduction of organisms (St. Clair and Howe 2007); (2) shifts in species ranges, including losses of species from the region (Rehfeldt et al. 2006); (3) altered disturbance regimes (including those generated by fire, insects and disease, and interactions among them, and by ocean-generated windstorms) (Littell et al. 2008); and (4) altered temperature and hydrological regimes of aquatic ecosystems (Mote 2003).

Climate change is expected to alter natural disturbance regimes in significant ways. Warming climate, especially during the fall, winter and spring, will cause later snowfall, reduced snow packs, and snow melt, reducing water available for use by plants and aquatic systems later in the growing season. This would result in earlier onset of summer drought than is currently typical of the region. Earlier droughts combined with elevated growing season temperatures could lead to longer fire seasons, reduced average fuel moisture levels, and increased extent of wildfire, including high severity fire which could destroy existing old forests (Franklin et al. 1992; Mckenzie et al. 2004; Westerling et al. 2006).

The pattern of ecological impacts from climate change will likely be influenced by variability in regional and local topography (Fig. 3). North–south trending mountain ranges intersect the west-to-east flow of marine air masses. Increases in moisture stress are expected to be greatest in drier forest and shrub-steppe ecosystems east of the Cascade Range where temperature increases are expected to be greatest (Littell et al. 2009). Empirical evidence suggests that the area of wildfire and stand replacing fire in drier forests of the region has been increasing over the last 25–30 years (Healey et al. 2008; Littell et al. 2009). Trends in fire in the wetter coastal areas are uncertain.

Insect outbreaks are also expected to increase. For example, outbreaks of the mountain pine beetle (*Dendroctonus ponderosae*) that are killing millions of hectares of lodgepole forest to the north in British Columbia, may move south in the eastern half of the PNW as pine trees are stressed over large areas by increased moisture deficits (Littell et al. 2009. In addition, positive feedbacks among climate change, pathogens, and carbon emissions may occur under altered climates (Kurz et al. 2008).

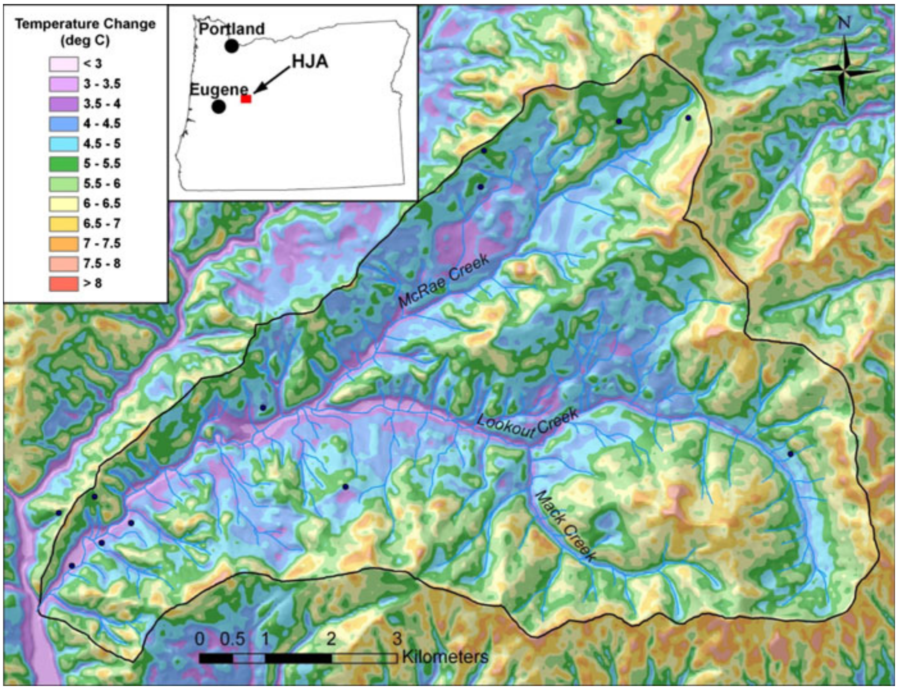

Fig. 3 Projected changes in maximum December temperatures in response to a 2.5°C regional temperature increase and changes in atmospheric circulation patterns in the Western Cascade Range. Results were based on regression models for 12 weather stations (indicated by *dots*) in the watershed using elevation and topography as explanatory variables. Daly et al. (2009)

Climate change is also expected to affect growth, vigor, and endemic mortality rates of many organisms in the region. We focus here on tree species, which play critical roles in habitat creation and ecosystem processes. Growth may increase for species at high elevations that have been temperature limited but decrease at lower elevations where water stresses increase (Littell et al. 2009). For example, Douglas-fir basal area growth has increased across the region over the 20th century—a trend that was correlated with increasing minimum temperatures (Littell et al. 2008). Negative growth effects would be expected where species are at the warm, dry edge of their range. Increasing rates of mortality of trees were reported recently in old-growth forests across the region during the last 30 years (van Mantgem et al. 2009). Changing mortality rates among species could result in different competitive interactions mediated through changes in light and available soil moisture. Such changes would likely affect composition and lead to novel communities.

Major changes in species distributions will result from the cumulative effects of disturbances and changes in energy and water limitations coupled with migration. For the most common species this may mean upward elevational and latitudinal shifts in their distribution on the landscape in response to changing moisture limitations. The distribution of the ubiquitous Douglas-fir may change considerably; one study projects that only 13% of its current range will be climatically suitable in the late 21st century (Rehfeldt et al. 2006). Douglas-fir is genetically diverse and its genetic patterns show close adaptations to local climatic variations that correspond with topography (Campbell 1986). Another study concludes that in a century Douglas-fir populations adapted to the local climates will have to come from elevations that are 450–1100 m lower and latitudes that are 1.8–4.9° (205–521 km at 43° N) further south (St. Clair and Howe 2007). Normal gene flow and migration patterns are highly unlikely to move such distances within the century (Aitken et al. 2008).

Major ecological concerns related to climate change

Although, the forest policies of the late 20th century were developed largely under the assumption of relatively stable climate, we believe the conservation strategy that has been implemented in the region provides a good foundation for developing conservation strategies in anticipation of climate change. We do not mean that climate change effects will be minimal. They could be quite large—but our recent policies on federal lands set the stage for undertaking conservation and adaptive actions, if we choose to take them.

We arrive at this conclusion based on the following observations. The percentage of forest land in the region dedicated to achieving conservation outcomes is much higher than most regions of the world (Fig. 1). For example, over 32% of the land within the NWFP area (23 million ha in the western half of the region) is dedicated to protection and maintenance of biological diversity and no intensive timber management, such as clear-cutting and plantation management, is permitted. This percentage is 2–3 times larger than the percentage of protected areas in North America and for mountain biomes globally (Chape et al. 2005). Where timber management activities are allowed protection of wildlife and fish habitat is required (such as significant stream buffers).

Connectivity of the natural forests of the region is relatively high for mid to high elevations because of ownership patterns. Public lands occur as large belts across mountainous regions and contain many large blocks of protected forests (Moeur et al. 2005). Connectivity is expected to improve as plantations of native species age and become more ecologically diverse (Spies et al. 2007). The prominence of wilderness areas, parks, and reserves at high elevations appears to provide connectivity and space for species from lower elevations to move upslope and north along mountain ranges (Fig. 1). Many non-federal forests—where biodiversity goals are secondary to timber production and other goals – are in coastal areas where warming from climate change is expected to be less extreme, at least over the next 30 years.

Despite the recent advances in protection of biodiversity, undesirable direct and indirect changes could occur as a result of climate change. Based on our ecological knowledge and other studies (e.g. Franklin et al. 1992; Rehfeldt et al. 2006; St. Clair and Howe 2007; Reiman et al. 2007; Littell et al. 2009; Olsen and Burnett 2009; van Mantgem et al.

2009) we anticipate that the most significant changes would be:

- Increases in rate of loss of large old pines and other conifers (and NSO habitat) to drought and high severity wildfire, especially where high fuel loadings result from accumulations of live and dead biomass;
- Increased water stress and insect mortality in large areas of dense stands in the drier central and eastern parts of the region—such stands may then burn at high severity when fire occurs;
- Extirpation of high elevation tree species, which have limited potential to move upslope or across complex topography, either at the population level (e.g. whitebark pine (*Pinus albicaulis*) or, at the species level in the case of regional endemics such as Brewer spruce (*Picea breweriana*);
- Increasing genetic maladaptation of widely-distributed tree species to their sites as a result of rapid climate change and relatively slow inherent rates of migration and gene flow; and
- Losses of habitat for aquatic species of cold-water mountain streams (e.g. bull trout (*Salvelinus confluentus*)) and headwaters, where stream temperatures rise and summer stream flow declines. Also, these species may find themselves isolated in drainages with limited potential for migration.

Possible adaptive actions for PNW forests

The following are examples of possible adaptive actions for forest management in general and for the PNW region specifically (Littell et al. 2009). Our list is not exhaustive and includes some controversial strategies (e.g., assisted migration and fuel reduction) that may prove ineffective or have unanticipated negative consequences.

Landscapes and disturbance regimes

Alter landscape structure to facilitate flow of organisms and/or alternatively to impede the spread of fire and pathogens

Connectivity of native forest habitats can facilitate movement of desirable organisms and impede movement of undesirable organisms (e.g. exotic plants). However, increased connectivity of dense forests in fire prone landscapes can also facilitate the spread of fire and insects. Consequently, increasing connectivity—a common recommendation regarding adaptation to climate change–needs to be examined carefully. Increasing connectivity to facilitate movement of species in response to climate change can come by promoting old-forest habitats (e.g. thinning to promote the development of large trees in plantations, and fire management to protect existing old forests) and structures, increasing the extent of riparian buffers, especially on non-federal lands where buffers are currently limited, and increasing connections across ridgelines to promote dispersal of headwater species (Olsen and Burnett 2009). On the other hand, reducing connectivity by breaking up contiguous patches of dense fuels in dry forest types or introducing heterogeneity into monocultures can reduce spread of fire and insects.

Increase landscape area devoted to providing critical habitats and resilient ecosystem types

This action would increase the safety margin against the loss of valued habitats (e.g. northern spotted owl and other old-forest associated species) to high-severity disturbances. For example on federal forests an option may be to manage the matrix lands (land currently intended for timber production, about 20% of total federal land)) to increase area devoted to producing critical habitats and climate and fire-resilient forests.

Manage wildfire to protect habitats/species at risk

Extra efforts to identify and protect existing critical habitat from wildfires in dry forest landscapes is logical given that large, old trees and habitats for some threatened and endangered species have already been reduced by decades of logging, fire and land-use change. This involves: (1) suppressing wildfires where they threaten critical old forest habitat patches and elements (e.g. large old trees); (2) treating stands by altering forest densities, composition and diameter distributions; (3) increasing spatial heterogeneity to create landscapes and ecosystems that are more resilient to fire, insects and disease (Finney et al. 2007; Johnson and Franklin 2009; North et al. 2009); and (4) using tactical treatments, such as shaded fuel breaks, to alter fire behavior and provide defensible spaces from which to fight fires. All of these actions, however, must take into account tradeoffs associated with silvicultural practices that reduce risk of high severity fire but eliminate habitat of species that use dense multistoried forests (e.g. northern spotted owl). In practice, this is extremely difficult to accomplish.

Use wildfires as an opportunity to facilitate establishment of current and future climate-adapted species and communities

While increased wildfires can be a threat to biodiversity, especially in landscapes where habitat has been altered by logging and land-use change, they also provide a benefit by creating diverse early successional conditions and opportunities for natural or artificial regeneration of new genotypes and species that may be better adapted to the climate than those in existing stands. The challenge to planners and managers is deciding when and where to allow fires to burn and what to do afterwards. The challenge is especially great where federal lands border state and private lands where wildfires can threaten commercial timber crops and homes.

Forest growth and vigor

Use variable density thinning in dense young stands to provide more resources to surviving individuals and promote resilience and species and structural diversity

Spatially heterogeneous thinning of dense young stands has promoted the growth and survivorship of remaining individual trees and, more recently, been used to accelerate the development of structurally and ecologically diverse conditions (Thomas et al. 1999). Such thinning could, in theory, also promote growth and vigor of the tree layer under warming climate, but no studies have examined this question. However, the duration of this effect and the degree to which it promotes undesirable understory growth is a major uncertainty. In addition, thinning and associated management activities can increase occurrence of invasive plants.

Maintain existing older forest

Large conifers are more resistant to drought and have lower mortality rates than smaller individuals (Phillips et al. 2003), and may be found in moist parts of the landscape that may be buffered against the effects of climate change. This resistance may result from deeper roots and greater water holding capacity than younger trees. Although mortality rates in old-growth forests have increased over the last few decades (van Mantgem et al. 2009), the very existence of centuries-old trees demonstrates that they can persist in the face of some level of climate variability.

Genetic diversity at intra- and inter-specific levels

Establish new genotypes and species to create communities that are adapted to current and future climates

The effectiveness of assisted migration for genotypes and species is not well understood and is controversial in the scientific community (Marris 2009). However, in theory this may be one way to improve resilience of maladapted local populations of common species and loss of rare species that cannot migrate fast enough to keep up with climate change. Initially one could consider moving and planting genotypes within the current range of the species. This certainly could occur when new plantations are established or when replanting after wildfire. Establishment of new genotypes and species often requires creating canopy openings in existing forests that are large enough to meet the light requirements of species. On federal lands, these management actions could be done within existing plantations and other younger forests. Additionally, experimental populations could be established outside the current ranges of the species as sources of seed and genetic material to facilitate natural gene flow and population migration.

Planning and monitoring

Identify potential refugia at regional and landscape levels where climate change may be buffered by local conditions

As noted above mountainous terrain will experience spatially variable levels of climate change (Daly et al. 2009) and harbor climate refugia. For example, some topographic positions subject to cold air drainages and topographic shading in the Oregon Cascades have old conifers that have persisted for more than

800 years with little fire (Giglia 2004). This variability can be used to prioritize actions describe above.

Use regional planning to coordinate changes across management units and jurisdictions

Given limited resources for adaptive actions, agencies will need to prioritize at regional scales across management units (e.g. national forests, parks, and wilderness areas) and across ownerships. Addressing climate change in a coordinated manner within management units and across all lands and landowners could enhance the effectiveness of adaptive responses.

Revise land management goals and objectives to be consistent with dynamic processes and uncertainty expected under climate change

Goal statements must find a delicate balance between being too specific about preservation of biodiversity and being so broad that they do not provide meaningful direction and constraints. Often this is framed as moving from goals based on preserving species and structures to goals based on processes and functions. For example, instead of seeking to restore forests to their historical range of variation in structure and composition, management may seek instead to create structures and landscape patterns that spread risk (through creating a diversity of conditions) or provide for resistance and resilience (e.g. maintaining large, fire resistant trees and species are adapted to drought and increase disturbances). But, basing planning and management on processes and functions (e.g., disturbance rates, productivity) is difficult and good examples are yet to be developed. The temporal scale of climate change and planning processes also need to be better aligned. Plans based on a typical 10 year horizon will not adequately address changes that will be occurring over many decades or centuries. Consequently, planning will need to take a multi-scale temporal view.

Use ecological history to help understand the dynamics and processes of ecosystems and species, but be careful when using history to set ecological goals

We often use historical data and trends to set conservation goals and build models about future impacts. Recent trends in climate and the prospect of climate change are forcing scientists, modelers, and managers to rely less on history as a reference. However, we can still learn from historical data to identify components of ecosystems that change rapidly when disturbed (Jackson and Hobbs 2009).

Incorporate uncertainty into planning as the new "normal" and make adapting to climate change a long-term, iterative process

Uncertainty is not new to managers but it is becoming more apparent and pervasive. This suggests that future management will include plans reflecting locally-specific conditions and monitoring of the implementation of those plans to increase learning opportunities. However, a long-term monitoring program can be a powerful way of detecting trends but it does not necessarily reveal cause and effect relationships. Uncertainty and climate change are likely to be with us for the long-term requiring dynamic and adaptive thinking integrated into the way we all think about change, conduct planning and management, and learn from changing conditions (e.g., Hallegatte 2009).

Acknowledge that not all climate change problems have solutions

Set priorities based on tractable problems. Some losses of forest biodiversity are inevitable, especially for species with small populations that are restricted to high elevations or are dependent on hydrological systems associated with snow packs. This will require new communication skills with a wide array of communities interested in regional forest management and climate change and a process to set priorities for decision makers.

Adaptation as a "double-edged sword"

Most, if not all of these potential actions pose both solutions and possible new problems (Table 1) and none can really be classified completely as "no regrets strategies" Hallegatte (2009) or without some potential ecological or socio-economic problems or barriers. Given the history and culture of controversies around federal forest management in the PNW

Table 1 Examples of the "double-edged sword" of ecological and social outcomes associated with adaptive actions for conservation under climate change

Adaptive action	Pros	Cons
Active management to create resilient forests and landscapes	Can increase capacity of forests and multiple species to resist and recover from fire, insects, disease and drought	May reduce habitat for some focal species (e.g. northern spotted owl), Costly Prescribed burning can reduce air quality Can increase carbon emissions Increase invasive and exotic plants
Moving and establishing new species and genotypes within and beyond their current ranges	May increase capacity of populations of native species to regionally persist and adapt to rapidly changing climate	May require socially unacceptable logging to create open environments for establishment Uncertain and unintended outcomes to communities and ecosystems Species and associated pathogens may become invasive May require changes in laws and policies
Using/managing wildfire (through variable suppression) to create/restore ecological diversity and resilience	Can create ecologically diverse early successional habitat that may be in short supply and provides opportunities for establishment of new genotypes Can reduce risk of future high-severity fire	May destroy older forest habitat that is in short supply Wildfires emit carbon Social resistance to wildfire management policies
Develop multi-ownership climate change strategies	Possibility for effective conservation actions	May require changes in laws and existing policies Politically difficult
Incorporate uncertainty into planning and management	May enhance adaptive learning and improve effectiveness of responses to climate change Risk-spreading reduces level of potential loss	Lack of general guidance and measures of success Mistrust may limit actions Cost and difficulty of adaptive management and monitoring

region, it seems likely that for some of these actions, the uncertainties and potential problems will likely limit adoption of these strategies and even become weapons in lingering philosophical debates about management of federal forests.

How well suited are current policies for adaptive actions?

Although our recent policies have created a strong foundation for conservation they are based on assumptions of stable climate that may make them poorly suited for undertaking adaptive actions in the PNW in response to climate change. There are two dimensions to this concern: First, objectives and language are not matched to new perspectives on species and ecosystem responses to climate change; second, current policies may not be flexible enough to allow adaptive actions.

The goals and terminology of laws and regulations vary in consistency with the scientific understanding of species and ecosystem behavior under changing climate. For example, some laws (TWA, NFMA, ESA) are focused on "preservation" (or extinction avoidance) of species and nature, which may not adequately address the ecosystem impacts of climate change. Craig (2010) argues that many of our environmental and natural resource laws, which are based on assumptions of ecological stationarity, do not account for needs for adaptation to a world of continuing climate change impacts. For example, she points out that under climate change it will be difficult to set ecological standards under the Clean Water Act, whose goal remains to "restore and maintain…the ecological integrity of the Nation's water." Likewise, for natural resources laws, it may be difficult to define sustainable yield or viability standards under climate change.

However, the language in all these laws may be general enough to allow new interpretations of what it means to conserve species and ecosystems under climate change. For example, although NFMA seeks to preserve the diversity of plant and animal communities based on the "suitability and capability of the land," there is no reason why potentially suitable areas cannot be seen as spatially dynamic. The ESA, perhaps the strongest US environmental law, permits a considerable amount of management activity related to habitat and manipulations of populations for the goal of species conservation. For example, it permits actions such as "propagation, live trapping, and transplantation," including movement of populations outside their current geographic area. It also permits establishment of "experimental populations" that are geographically separate from the main populations. Establishment of new populations of grey wolves across the western U.S. is a good example of this policy (Bangs et al. 1998).

Much of the change in US environmental policy comes through the rewriting of the regulations implementing the laws rather than the laws themselves, a task over which the Executive Branch has considerable discretion. As an example, regulations to implement the NFMA issued in 1982 focused on sustainable timber harvest and providing for biodiversity of plant and animal communities (USDA 2010). They were reissued in 2000 focused on ecological, economic, and social sustainability with very little of the language and concepts of the previous regulations surviving (USDA 2010) and they are currently being revised again. Over time, the courts have afforded the Secretary of Agriculture considerable deference in this evolution of explanation of what the law means as long as the actions followed the legal processes for regulation change.

Climate change strategies and responses in anticipation of climate change for national parks and wilderness areas have not yet been established, but management of these lands has evolved over time in response to changes in scientific knowledge and society. It is quite likely that adaptive actions will be accommodated within the environmental laws and policies that govern these lands (Baron et al. 2009).

In summary, current laws often are based on concepts of stationarity and preservation, but have language that is also broad and appears to permit adaptive actions and the regulations written by the Executive Branch to implement these laws potentially can be rewritten to incorporate needed changes. However, the question of the whether current laws and regulations allow sufficient flexibility to undertake a wide range of adaptive actions may be answered only through the case law that develops in response to proposed actions.

Socio-economic influences

While existing policies may provide the flexibility to undertake adaptive actions on federal lands to improve conservation outcomes under climate change, it is not clear that managers and policy makers will have the social license and funding to implement those policies. The history of federal management in the region is characterized by discrepancies between policies and law on the one hand, and what happens on the ground on the other. These discrepancies are driven by social and economic forces. The laws and policies, which leave considerable room for interpretation and variation in implementation (Hays 1989) are indeed interpreted and implemented differently by each generation of citizens, courts, and government employees. For example, during the period of sustained yield forestry on federal lands (roughly 1950 to late 1980s) (Johnson and Swanson 2009), timber production goals were dominant despite the passage of the Multiple-Use Sustained Yield act of 1960, which recognized that the National Forests were created to produce multiple values in addition to timber. As litigation forced managers to closely follow environmental laws during the late 1980s and early 1990s, the ecological goals as expressed in ESA, NFMA, NWFP and other policies became dominant (Keiter 2003). Region 6 of the Forest Service (Oregon and Washington) experienced more than twice as much litigation as any other region in the U.S. and much of this concerned challenges under NEPA (Keele et al.

2006). Many of the challenges were related to logging projects, suggesting that adaptation strategies that involve logging may continue to be controversial. The litigative process in the PNW region and the U.S. has played out over 20 years, and interpretations and policies regulating forest practices continue to evolve. Economic constraints are playing a role as well. For example, the funding needed to effectively reduce the risks of high-severity fire has not been considered adequate (Stephens and Ruth 2005) and adaptive management, as prescribed under the NWFP, has not been practiced, in part, because of lack of funds.

Successful conservation of species and ecosystems under climate change is likely to require system-level goals and approaches that do not rely on objectives to preserve particular species or places over a long period. Experiences with applying management actions based on disturbance theory in the Blue River watershed on the Willamette National Forest, indicate, however, that the public may not understand or agree with management activities that use logging to emulate natural disturbances or other more abstract ecological goals, especially if it involves removing old trees (Cissel et al. 1999; Shindler and Mallon 2009). Such social constraints could affect the ability of managers to manage forests to increase "resilience" or create openings large enough to establish locally adapted geneotypes of species.

The availability of social license and funding needed to manage federal forests with respect to climate change can impose significant limitations in implementing management actions to conserve species and ecosystems. However, as in the past, political and legal processes and economic forces are likely to be significant drivers of what happens on federal lands in the PNW region. Understanding and engaging this process to ensure effective management actions and policies regarding biodiversity on federal lands will require new efforts in adaptive management and engagement with the various stakeholders.

Adaptive management

Given the uncertainties related to climate change, ecological and social responses to change, more effective adaptive management strategies including monitoring are needed. The adaptive management program which no longer exists under the NWFP had limited success (Stankey 2009). Limited funding and social resistance to new forms of forestry reflect an aversion to cutting of old trees and other concerns; and landscape-level approaches have been nearly impossible to implement and monitor.

Despite these challenges, we have learned some lessons from the experiments in adaptive management. Those experiences suggest that an adaptive management process should include the following:

- Integrated regional monitoring for trend detection with targeted process studies and experimental work to elucidate cause and effect, including separating climate effects from land-use and other drivers of ecological change to the extent possible;
- Place-based, collaborative learning efforts involving scientists, managers, regulators and various publics. These should distributed across environmental gradients from low to high expected change The value of these interactions will be two-fold: learning about adaptive actions, and more importantly, learning how to *think* about climate change, including the changes that humans will have little control over;
- Monitoring and evaluation of social attitudes regarding climate change and potential management responses. It is clear that much of the change in forest management over the last century is a result not just of new ecological and silvicultural knowledge, but also changes in how society values forests. A better understanding of these complex processes will lead to more effective decision making about forests;
- Developing institutions to help cope with the difficulty of agencies evaluating their own policies. Monitoring can help if there is willingness to react to evidence of policy failure. Periodic independent review and other mechanisms that enable fresh looks at policy success will be needed;
- Reenergizing resource professionals as an early warning system about environmental change. A cadre of knowledgeable professionals in the field can be a cost effect way for learning about and coping with environmental change; and
- Addressing the ethical, moral, and conceptual issues associated with environmental change. While past PNW conflict was (mis-)cast as a

simple "owls vs. jobs" conflict, the coming challenges of climate change are vastly more complex, and attention must be paid to casting differences in perspectives more accurately and usefully. Participation by historians, philosophers, creative writers, and others in the arts and humanities could help us learn how to think and feel about climate change. How the media communicates these complex issues may have the strongest effect on how society deals with climate change.

One lesson from examining the socio-ecological system of the PNW public forests is that the decision-making process involves many actors in multiple sectors, each with their own perspectives and demands, and all with a significant influence on the process. Consequently, as uncertainties increase with the changing climate, we need to engage in processes (e.g. collaborative learning efforts involving various stakeholder groups) that help us learn how to think about dynamic ecosystems and climate change.

Conclusions

Large changes in the climate of the PNW are highly likely to occur but the effects will vary significantly across this topographically diverse region. Many of the policies and practices that were established to conserve biodiversity under the assumption of a stable climate appear to provide a good starting place for conserving biodiversity under a changing climate. However, undesirable and unanticipated changes will occur, but these may be tempered by planned adaptive actions. These actions include changes in stand and landscape management practices as well as in approaches to planning. The strong and spatially prescriptive laws and policies that are now in place do provide some flexibility for taking adaptive actions. Nevertheless, the suitability of these policies for adapting management in response to climate change is uncertain since they have been ecologically and socially double-edged swords in the past. The potential to implement effective adaptive actions will be revealed through social processes including public relations campaigns, litigation and economic decision making. Management practices that include both ecological and social systems monitoring will help all of us understand the complex changes occurring on the landscape and in the minds of citizens. This integration of ecological and social sciences is needed to better understand how feedbacks and interactions affect ecosystems and decision making, and to reveal tradeoffs associated with different scenarios of landscape change and management.

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