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Climatic Variability in Eastern Oregon and Washington

Abstract

Climate is a driving factor in forest health and productivity that limits species survival and affects disturbance processes. Complex topography and mosaics of land cover compound the variability of climate in eastern Oregon and Washington. The area is a transition zone between marine, arctic, and continental influences with associated extremes in weather. Such extremes affect insect populations, animal migration, streamflow, flooding, and wildfire potential. Additionally, human activities such as deforestation and atmospheric pollution interact with climate, and may cause changes similar in magnitude to the glacial-interglacial epoch in the next 50 to 100 years. Effects of anthropogenic climate changes are ambiguous, however, and could counter-balance each other. For example, tree populations may have more difficulty reestablishing, but growth rates could accelerate. Conversely, management actions can mitigate the effect of climate on fisheries, water resources, wildfire, and floods. Also, management actions can affect climate by modifying carbon exchange and water and energy exchange between land and atmosphere. Models are increasingly able to predict climate variability and trends in climate-related disturbances such as wildfire.

Basic Knowledge

Climate is an important influence on ecosystems and processes. By understanding climate and its effects, we can alter site- to stand-level management strategies and mitigate the effects of variability and trends in larger-scale climate.

Climate of eastern Oregon and Washington is highly variable in both time and space. The temporal variability is caused by (1) being in a transition zone between maritime, continental, and arctic influences (Mitchell 1976; Ferguson 1995, 1998a), (2) influences from oscillations between the ocean and atmosphere such as the El Niño Southern Oscillation (ENSO) (Meko and Stockton 1984; Cayan and Webb 1992, 1996; Cayan and Redmond 1994) and the Pacific Decadal Oscillation (PDO) (Wallace and Gutzler 1981, Mantua et al. 1997, Mote et al. 1999a), and (3) having a mid-latitude position that makes the region highly susceptible to changes in global radiative energy, or greenhouse gas effects (Ferguson 1995, Houghton et al. 1996, Leung and Ghan 1999). The spatial variability is a result of shifting patterns in seasonal storm tracks and, because the region is very near the confluence zone of the polar jet stream, winter climate varies considerably from year-to-year. Summer climate is less variable because of a persistent high pressure in the eastern Pacific. Both temporal and spatial variability patterns are most apparent at watershed to larger scales. All scales, however, from organism levels upward, experience a heterogeneity in climate patterns that is due to the complex topography and mosaics of land cover found in the region, each of which respond differently to larger scale changes in climate conditions (Mock 1996). This causes the impacts of climate variability to be manifested at local to regional scales.

The ENSO fluctuations are random, varying from 2 to 7 years (Figure 1) between a warm phase (El Niño) and a cold phase (La Niña) (Neelin et al. 1998). Both phases impact regional temperature more strongly than precipitation and impact winter and spring conditions more strongly than other seasons (Mote et al. 1999a). During the warm phase (El Niño) the Pacific Northwest usually experiences its driest winters with warmer winter and spring temperatures. During strong El Niños (for example, 1982-1983 and 1997-1998) only the anomaly in temperature is amplified. The precipitation response is more ambiguous (Mote et al. 1999a). The Pacific Northwest response to the cold ENSO phase (La Niña) is less pronounced but there is some evidence of cooler winter and spring temperatures. The ENSO cycle has become increasingly predictable and several months of advance warning are possible (Neelin et al. 1998).

The quasiperiodic changes in PDO tend to occur every 10 to 30 years (Figure 2), with cool, wet cycles during 1900 to 1925 and 1945 to 1977 and warm, dry cycles during 1925 to 1945 and since 1977 (Wallace and Gutzler 1981, Trenberth 1990, Ebbesmeyer et al. 1991, Mantua et al. 1997, Mote et al. 1999a). Evidence of a recent shift to a cool,

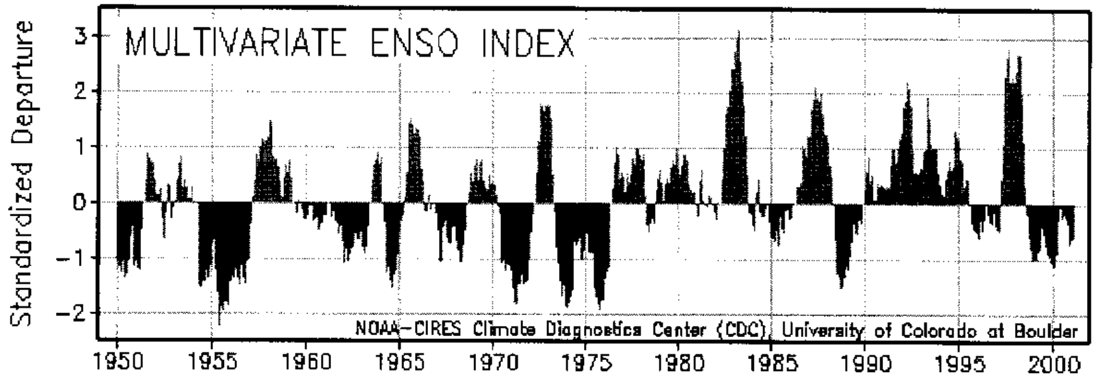

Figure 1. Time-series of a multivariate ENSO index from the National Oceanographic and Atmospheric Administration, Cooperative Institute for Research in Environmental Studies, Climate Diagnostics Center, University of Colorado, Boulder. Positive departure indicates warm-phase events (El Niño). Negative departure indicates cold-phase events (La Niña).

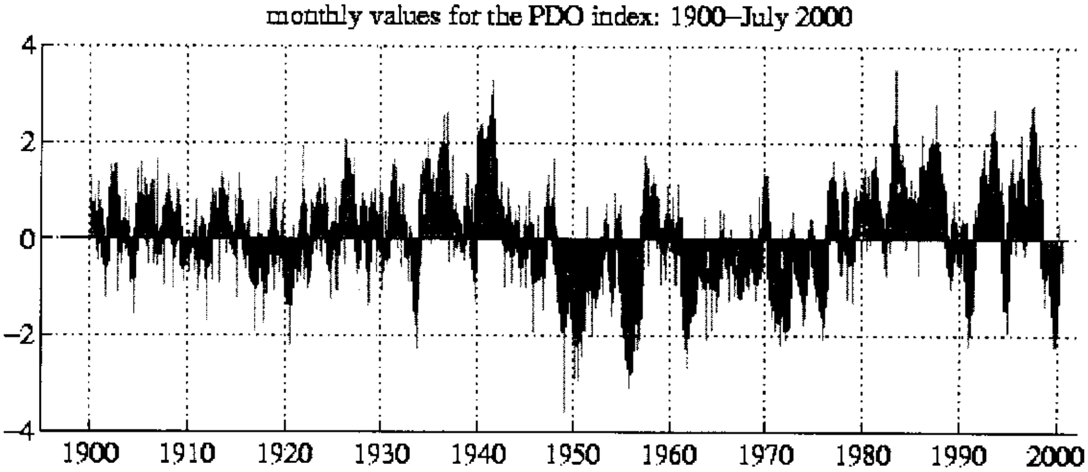
monthly values for the PDO index: 1900–July 2000

Figure 2. Time series of a PDO index from the Joint Institute for the Study of the Atmosphere and Ocean, University of Washington, Seattle. Dry phases are positive indexes and wet phases are negative indexes. (http://jisao.washington.edu/pdo)

wet PDO cycle is mounting but has not been confirmed (Trenberth and Hurrel 1995; Hare and Mantua, *In press*). There is some evidence that ENSO and PDO are related, as more frequent and greater magnitude ENSO events occur during a dry PDO, while less frequent and less dramatic ENSO events occur during a wet PDO (Zhang et al. 1997, Gershunov and Barnett 1998, Mote et al. 1999a).

Observed increases in greenhouse gases since about 1800 are thought to have caused changes in global radiative energy resulting in pronounced global warming (Houghton et al. 1996). The regional impacts of global warming could cause increases in winter temperatures, increases in nighttime temperatures during all seasons, increases in precipitation during winter, spring, and fall, slight decreases in summer precipitation except in southeastern Oregon, and increased atmospheric stability, especially during winter (Giorgi et al. 1994, Ferguson 1997, Mote et al. 1999a, Leung and Ghan 1999).

Effects of Climate

Being in a transition zone causes seasonal climates to be moderated as marine, arctic, and continental influences interplay. Few severe weather events occur and relatively mild conditions prevail, with mean monthly temperatures ranging from -10 to -3°C in winter and from 10 to 20°C in summer (Ferguson 1998a). The change between influencing climate regimes can, however, create significant weather disturbances. For example, when arctic-like weather patterns, which freeze soils and create low-elevation snow accumulations, are followed directly by maritime weather patterns with warming temperatures and rain, snowslides, landslides, and floods may occur (Jensen et al. 1997, Ferguson 2000). These events can significantly alter riparian habitats and other site- to stand-level attributes. When the reverse occurs, mild maritime conditions followed by cold arctic weather, freezing damage to vegetation is possible, usually affecting stand to subwatershed scales (Quigley and Arbelbide 1997, p. 194-196).

The interplay of climate regimes also impacts summer weather. When dry, continental conditions prevail, efficient drying of biomass fuels occurs, creating significant fire potential. The influx of marine air can either remoisten fuels or, if low-level moisture is trapped by the coastal mountains and confined to high elevations as it moves eastward, rapid instability can occur causing outbreaks of lightning and wildfire ignition (Rorig and Ferguson 1999).

Seasonal variations in climate, which often can be related to ENSO, can cause changes in insect populations, animal migration patterns, streamflow, flooding, and wildfire potential. For example, insect populations can completely disappear during extremely cold winters (Greenbank 1970). Snowcover and streamflows tend to be less than average during an El Niño year (Meko and Stockton 1984; Gutzler and Rosen 1992; Cayan and Webb 1992, 1996). Heyerdahl (1997) deduced that seasonal fire activity fluctuates in places where the fire season is bounded by snowcover, like the northern regions of the Blue Mountains. During El Niño years, less low-elevation snow can extend the fire season, providing more opportunity for ignition and spread among the dry fuels. Fire activity in places where seasons are less controlled by snow, such as the southern regions of the Blue Mountains, respond less noticeably to variations in seasonal climate. This is because fire potential depends on the likely sequence of weather that dries fuels, provides sources of ignition (for example, lightning), and causes spread (such as wind and deep atmospheric instability) (Lenihan et al. 1998). For example, although the 1988 fire season was drier than normal, it would have been unremarkable if it were not for a greater frequency of gusty winds from numerous cold frontal passages (Jensen et al. 1997). While lightning frequency is thought to be relatively consistent from year-to-year, new efforts to match lightning occurrence to large-scale forcing patterns (Rorig and Ferguson 1999) may allow better understanding of seasonal variability of fire ignition potential.

Decadal variations in climate are related to insect outbreaks and large wildfires. For example, the most recent dry PDO since 1977 is characterized by a period of enhanced wildfire activity and devastating insect outbreaks (Ottmar et al. 1998). Also, paleoclimate records show decadal variations in insect populations and the frequency of fire. Outbreaks of sap-sucking insects (for example, bark beetles) commonly occur during warm, dry periods when trees are experiencing drought stress (Swetnam and Lynch 1993). Wet cycles, however, can favor foliage feeders, such as spruce budworm (Swetnam and Betancourt 1998). Both Heyerdahl (1997) and Mote et al. (1999b) found correlations between fire occurrence and interdecadal climatic variability. Heyerdahl speculates that this is due to the extended period of time in which fuels are dry, providing increased opportunity for ignition and spread.

Growth and regeneration of vegetation also are susceptible to climate variability, especially near timberlines and at the margins of habitats. Ponderosa pine (*Pinus ponderosa*) growth rates have been shown to decrease during dry phases of the PDO and increase during wet phases (Peterson and Peterson, *In press*). Depth and duration of snowpack also influence tree growth (Franklin et al. 1971, Peterson 1998).

Long-term trends in climate could alter disturbance regimes, habitat, stand structure and composition (Melillo et al. 1996, Bytnerowicz 1997, Mote et al. 1999a). Observed effects of climate change on vegetation composition as determined from local pollen records indicate that major shifts in dominant tree species occurred during glacial-interglacial epochs (Graumlich and Brubaker 1995, Bartlein and Whitlock 1997). Potential future changes similar in magnitude to the glacial-interglacial epochs are thought to be possible within the next 50 to 100 years due to deforestation and human introduction of pollution into the atmosphere (Melillo et al. 1996, Bytnerowicz 1997, Ferguson 1997, Mote et al.

1999a). The effect of anthropogenic climate change on vegetation is somewhat ambiguous, however, (Watson et al. 1998). While increased greenhouse gases could cause a warmer climate, which can stress vegetation and cause dieback or decline (Neilson and Drapek 1998), enhanced fertilization from increasing carbon dioxide and nitrogen could counter balance the effects of warming. If warmer temperatures are accompanied by increasing precipitation, forests could expand into neighboring shrub and grasslands (Franklin et al. 1971, Neilson and Drapek 1998). In either case, the amount of forest area and the composition of forests and rangelands could change (Franklin et al. 1991, Neilson 1993, Neilson and Drapek 1998, Neilson et al. 1998), altering the balance between evergreen and deciduous vegetation (Chapin 1991, Davis and Zabinski 1992, Neilson 1995, Neilson and Drapek 1998, Neilson et al. 1998). Also, increasing industrial pollutants and their reactants, such as ozone and sulfur dioxide, could promote early aging and reduced photosynthesis (Allen and Amthor 1995, Melillo et al. 1996, Brace et al. 1999).

In addition to changing growth and distribution patterns, long-term warming of the climate could alter disturbance regimes such as wildfire (Johnson et al. 1990, Johnson and Larsen 1991, Johnson and Wowchuk 1993, Wotton and Flannigan 1993). Because disturbance facilitates plant migration, changing vegetation structure and composition could proceed rapidly in areas affected by disturbance (Davis and Botkin 1985).

Risks

Traditionally, treelines have been the most susceptible to changing climates (Mote et al. 1999a; Peterson and Peterson, *In press*). If landscapes are fragmented, however, they may be susceptible through a deeper extent of their habitat range because of potentially fewer regeneration sites. This suggests that populations, which were established 100 to 500 years ago when the climate was distinctively cooler than it is now, may have difficulty reestablishing in the current warmer climate conditions. Fragmentation also creates edges that are susceptible to disturbance such as wind damage (Tang et al. 1997) and microclimatic change such as altered snow distribution, freezing potential, and solar drying. As landscape fragments decrease in size, heterogeneity decreases (Davis and Zabinski 1992). This lack of diversity further increases the susceptibility of vegetation to disturbance (Norton 1992).

A report by the Intergovernmental Panel on Climate Change (Watson et al. 1998) summarized the susceptibility of North American forests. For example, as climate changes, periods conducive to establishment may become less frequent. This could prevent regeneration even where mature trees still survive, precipitating some conversion of northwest conifers to broadleaf deciduous. While biomes are expected to shift northward and upward in altitude, expansion may be limited by poor soils or inefficient seed and pollen dispersal.

Because of its mid-latitude position, steep topography, and 3-part transient climate (maritime, continental, and arctic) the Pacific Northwest is particularly susceptible to climate variability and change (Mitchell 1976; Wallace and Gutzler 1981; Ferguson 1995, 1998a; Meko and Stockton 1984; Cayan and Webb 1992, 1996; Cayan and Redmond 1994; Houghton et al. 1996; Mantua et al. 1997; Mote et al. 1999a; Leung and Ghan 1999). For example, small changes in temperature can cause significant depletion of the snow cover and insect populations. Subtle changes in precipitation frequency can significantly alter fire regimes or prescribed fire potential.

Effects of Climate Adaptation Strategies

Lamb et al. (1986) recognized that incorporating climate information into land management strategies could lead to more effective management of forest resources, with clear monetary advantages. There is evidence that management strategies can mitigate the effect of climate on fisheries and water resources (Costello et al. 1988, Bottom 1995, Pulwarty and Redmond 1997). Also, the frequency and severity of rain-on-snow floods are affected by management strategies (Harr 1986, Harr and Coffin 1992). An aggressive prescribed fire program (USDI and USDA 1995) has been suggested as a way of reducing fuels in the hopes of mitigating severe wildfire potential that may be possible in a dry climate (Ottmar et al. 1998). Carey et al. (1999) recommend renewing or maintaining biodiversity in natural ecosystems as a way of guarding against inevitable changes in climate.

Because a tree is most susceptible during its first few years of growth, attention to local variations in climate patterns can help avoid areas of vulnerability when establishing forest plantations (e.g., Timmis et al. 1994). Also, predictions of annual to decadal climate may help anticipate changes during infancy. As the tree grows, it becomes less susceptible to short-term fluctuations in weather and climate, except by disturbance, but its productivity is affected by long-term changes in climate (Thornley and Cannell 1996; Joyce and Birdsey 1995). Use of bio-geographical models such as MAPSS (Neilson 1993, 1995; Neilson and Drapek 1998; Neilson et al. 1998) may show species that are more adapted to expected climate change and offer alternative planting strategies. Also, it may be possible to produce genotypes that are adapted to expected changes in water stress, temperature, and nutrient availability.

Little if any literature exists on adaptations for climate impacts on wildland rehabilitation projects or short-rotation forestry. Lessons can be learned from the agricultural industry, however, where climate impacts on crop yield (e.g., Coakley 1979) and use of seasonal-to-decadal climate predictions (e.g., Mauget and Upchurch 1999) are reported. The work implies that strategies to ensure survival of seedlings (grass, shrubs, and young trees) might consider using ENSO predictions and knowledge of PDO patterns.

In addition to the effect of climate on ecosystems, land management activities may influence climate by modifying the exchange of carbon (a prominent greenhouse gas component) and altering the water and energy exchange between the land surface and atmosphere. For example, harvest and prescribed fire programs release carbon to the atmosphere through decay and burning, respectively. On the other hand, post-harvest regrowth can enhance carbon storage (Mellilo et al. 1996). As forests age, their rate of carbon uptake decreases.

Simply changing the vegetation structure also can affect climate. The flux of heat and energy between the biosphere and atmosphere is partially controlled by a roughness parameter that depends on the height of the vegetation. This causes tall forests to exhibit much larger conductance than short grasslands (Schulze et al. 1994).

Decision-Support Tools and Thresholds

Recently, it has become increasingly apparent that much of the observed climate variability (for example, the ENSO and PDO) is predictable (Neelin et al. 1998, Mote et al. 1999a). Also, the impact of climate variability on disturbance such as wildfire is increasingly understood (Heyerdahl 1997, Mote et al. 1999b). This suggests that it may be possible to plan fire fighting resources or prescription programs well in advance. Hilbruner et al. (1998) used ENSO forecasts and fire history of the Northwest to anticipate fire resources needed to combat wildfires during the 1998 season. ENSO forecasts are available from the U.S. Department of Commerce, Climate Diagnostics Center. The stronger the episode, the more likely that regional impacts will occur.

PDO forecasts are not yet available and it still is uncertain whether the warm, dry PDO cycle, which began in 1977 has changed to the cool, wet period or not (Hare and Mantua, *In press*). A change is imminent, however, and it is commonly believed that the next 10 to 30 years could be cool and wet. If true, the relatively frequent and severe fire regime observed in the 1980s (Ottmar et al. 1998) may revert to a more benign regime typical of the 1960s. It is difficult to predict fire regimes confidently, however, because of uncertainty in the timing of major ignition events (such as dry lightning), the abundance of fine fuels following wet winters, and other complicating factors.

A potential trend in climate due to anthropogenic influences could increase annual average temperatures about 1 degree Celsius over the next 50 to 100 years, with the greatest increases expected during winter at low elevations where up to 3°C increases are possible (Ferguson 1997). Potentially warmer temperatures could reduce the magnitude of rain-on-snow floods, increase wildfire potential, and reduce spring runoff. This could cause a northward migration of species as well as migration to higher elevations. In addition to temperature increases, precipitation can increase during global warming, with winter precipitation increasing by as much as 20 to 50% and increases of 5 to 35% possible in spring and autumn (Giorgi et al. 1994, Ferguson 1997, Leung and Ghan 1999). These changes could increase winter runoff and reduce opportunities for prescribed fire in spring and autumn. Other regional implications of global warming include weaker temperature inversions during winter that could reduce pollution episodes, higher mixing heights during summer that would improve smoke dispersion, and fewer but stronger winter cyclones (Ferguson 1997, 1998b).

Climate influences all ecosystems. Each component of the system, however, has different thresholds of vulnerability. A 30% increase in springtime precipitation could effect flooding if it occurs in a few, large-magnitude storms or it could reduce drying times needed for fire ignition if it occurs in frequent small storms. Knowledge of dynamic processes in each ecosystem component can help determine thresholds that define required levels of management strategies. The uncertainty of climate predictions often forces strategies to expect change without committing to a direction or magnitude of change.

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