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Fire Ecology

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Chapter 2

REVIEW

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Changing wildfire, changing forests: the effects of climate change on fire regimes and vegetation in the Pacific Northwest, USA

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Abstract – left justified

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Background: Wildfires in the Pacific Northwest (Washington, Oregon, Idaho, and western Montana, USA) have been immense in recent years, capturing the attention of resource managers, fire scientists, and the general public. This paper synthesizes understanding of the potential effects of changing climate and fire regimes on Pacific Northwest forests, including effects on disturbance and stress interactions, forest structure and composition, and post-fire ecological processes. We frame this information in a risk assessment context, and conclude with management implications and future research needs.

Results: Large and severe fires in the Pacific Northwest are associated with warm and dry conditions, and such conditions will likely occur with increasing frequency in a warming climate. According to projections based on historical records, current trends, and simulation modeling, protracted warmer and drier conditions will drive lower fuel moisture and longer fire seasons in the future, likely increasing the frequency and extent of fires compared to the twentieth century. Interactions between fire and other disturbances, such as drought and insect outbreaks, are likely to be the primary drivers of ecosystem change in a warming climate. Reburns are also likely to occur more frequently with warming and drought, with potential effects on tree regeneration and species composition. Hotter, drier sites may be particularly at risk for regeneration failures.

Conclusion: Resource managers will likely be unable to affect the total area burned by fire, as this trend is driven strongly by climate. However, fuel treatments, when implemented in a spatially strategic manner, can help to decrease fire intensity and severity and improve forest resilience to fire, insects, and drought. Where fuel treatments are less effective (wetter, high-elevation, and coastal forests), managers may consider implementing fuel breaks around high-value resources. When and where post-fire planting is an option, planting different genetic stock than has been used in the past may increase seedling survival. Planting seedlings on cooler, wetter microsites may also help to increase survival. In the driest topographic locations, managers may need to consider where they will try to forestall change and where they will allow conversions to vegetation other than what is currently dominant.

Keywords: adaptation, climate change, disturbance regimes, drought, fire regime, Pacific Northwest, regeneration, vegetation

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Resumen

Antecedentes: Los incendios de vegetación en el Noroeste del pacífico (Washington, Oregon, Idaho, y el oeste de Montana, EEUU), han sido inmensos en años recientes, capturando la atención de los gestores de recursos, de científicos dedicados a los incendios, y del público en general. Este trabajo sintetiza el conocimiento de los efectos potenciales del cambio climático y de los regímenes de fuego en bosques del noroeste del Pacífico, incluyendo los efectos sobre las interacciones entre disturbios y distintos estreses, la estructura y composición de los bosques, y los procesos ecológicos posteriores. Encuadramos esta información en el contexto de la determinación del riesgo, y concluimos con implicancias en el manejo y la necesidad de futuras investigaciones.

Resultados: Los incendios grandes y severos en el Noroeste del Pacífico están asociados con condiciones calurosas y secas, y tales condiciones muy probablemente ocurran con el incremento en la frecuencia del calentamiento global. De acuerdo a proyecciones basadas en registros históricos, tendencias actuales y modelos de simulación, condiciones prolongadas de aumento de temperaturas y sequías conducirán a menores niveles de humedad, incrementando probablemente la frecuencia y extensión de fuegos en el futuro, en comparación con lo ocurrido durante el siglo XX. Las interacciones entre el fuego y otros disturbios, son probablemente los principales conductores de cambios en los ecosistemas en el marco del calentamiento global. Los incendios recurrentes podrían ocurrir más frecuentemente con aumentos de temperatura y sequías, con efectos potenciales en la regeneración de especies forestales y en la composición de especies. Los sitios más cálidos y secos, pueden estar particularmente en riesgo por fallas en la regeneración.

Conclusiones: Los gestores de recursos no podrían tener ningún efecto sobre el área quemada, ya que esta tendencia está fuertemente influenciada por el clima. Sin embargo, el tratamiento de combustibles, cuando está implementado de una manera espacialmente estratégica, puede ayudar a reducir la intensidad y severidad de los incendios, y mejorar la resiliencia de los bosques al fuego, insectos, y sequías. En lugares en los que el tratamiento de combustibles es menos efectivo (áreas más húmedas, elevadas, y bosques costeros) los gestores deberían considerar implementar barreras de combustible alrededor de valores a proteger. Cuando y donde la plantación post fuego sea una opción, plántulas provenientes de diferentes stocks genéticos de aquellos que han sido usados en el pasado pueden incrementar su supervivencia. La plantación de plántulas en micrositios más húmedos y fríos podría ayudar también a incrementar la supervivencia de plántulas. En ubicaciones topográficas más secas, los gestores deberían considerar evitar cambios y donde estos sean posibles, permitir conversiones a tipos de vegetación diferentes a las actualmente dominantes.

Abbreviations

ENSO: El Niño-Southern Oscillation
MPB: Mountain Pine Beetle
PDO: Pacific Decadal Oscillation

Introduction

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Large fires are becoming a near-annual occurrence in many regions globally as fire regimes are changing with warming temperatures and shifting precipitation patterns. The US Pacific Northwest (states of Washington, Oregon, Idaho, and western Montana, USA; hereafter the Northwest) is no exception. In 2014, the largest wildfire in recorded history for Washington State occurred, the 103 640 ha Carlton Complex Fire (Fig. 1). In 2015, an extreme drought year with very low snowpack across the Northwest (Marlier et al. 2017), 688 000 ha burned in Oregon and Washington (Fig. 2), with over 3.6 million ha burned in the western United States. Several fires in 2015 occurred in conifer forests on the west (*i.e.*, wet) side of the Cascade Range, including a rare fire event in coastal temperate rainforest on the Olympic Peninsula. In some locations, short-interval reburns have occurred. For example, one location on Mount Adams in southwestern Washington burned three times between 2008 and 2015 (Fig. 3). Similarly, during the summer of 2017 in southwestern Oregon, the 77 000 ha Chetco Bar Fire burned over 40 000 ha of the 2002 Biscuit Fire, including a portion of the Biscuit Fire that had burned over part of the 1987 Silver Fire. At over 200 000 ha, the Biscuit Fire was the largest fire in the recorded history of Oregon.

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Over the twentieth century in the Northwest, years with relatively warm and dry conditions have generally corresponded with larger fires and greater area burned (Trouet et al. 2006; Westerling et al. 2006; Littell et al. 2009; Littell et al. 2010; Abatzoglou and Kolden 2013; Cansler and McKenzie 2014; Dennison et al. 2014; Stavros et al. 2014; Westerling 2016; Kitzberger et al. 2017; Reilly et al. 2017; Holden et al. 2018). Decreasing fuel moisture and increasing duration of warm, dry weather creates large areas of dry fuels that are more likely to ignite and carry fire over a longer period of time (Littell et al. 2009).

A warming climate will have profound effects on fire frequency, extent, and possibly severity in the Northwest.

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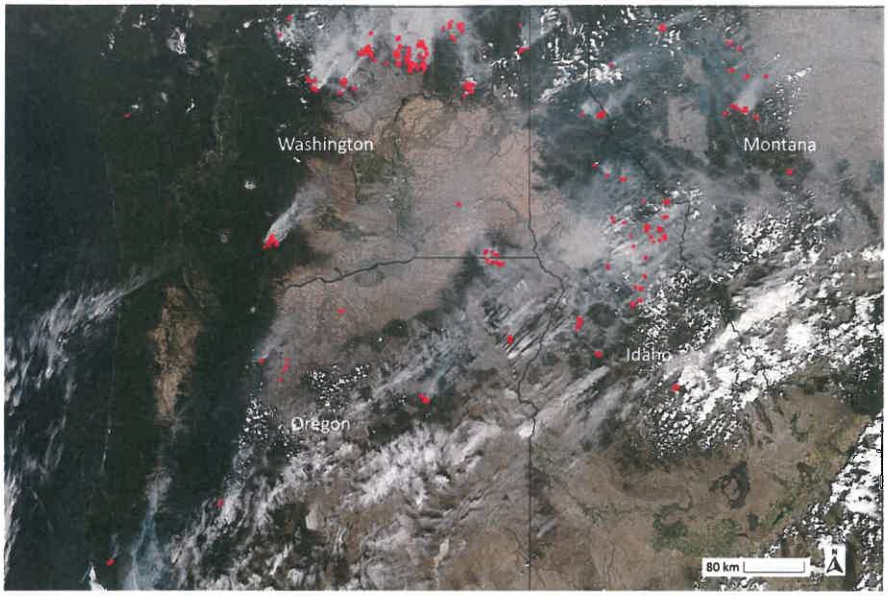

Fig. 2 Fires burning across the Pacific Northwest, USA, on 25 August 2015. This natural-color satellite image was collected by the Moderate Resolution Imaging Spectroradiometer (MODIS) aboard the Aqua satellite. Actively burning areas, detected by MODIS's thermal bands, are outlined in red. National Aeronautics and Space Administration image courtesy of Jeff Schmaltz, MODIS Rapid Response Team

2013; Safeeq et al. 2013); streamflow magnitude (Hidalgo et al. 2009; Mantua et al. 2010); and soil moisture content (McKenzie and Littell 2017). Compared to the historical period from 1976 to 2005, 32 global climate models project increases in mean annual temperature for the middle and end of the twenty-first century in the Northwest. These projected increases range from 2.0 to 2.6 °C for mid-century (2036 to 2065) and 2.8 to 4.7 °C for the end of the century (2071 to 2100), depending on future greenhouse gas emissions (specifically representative concentration pathway 4.5 or 8.5; Vose et al. 2017). Warming is expected to occur during all seasons, although most models project the largest temperature increases in summer (Mote et al. 2014). All models suggest a future increase in heat extremes (Vose et al. 2017).

Changes in precipitation are less certain than those for temperature. Global climate model projections for annual average precipitation range from −4.7 to +13.5%, averaging about +3% among models (Mote et al. 2014). A majority of models project decreases in summer precipitation, but projections for precipitation vary for other seasons. However, models agree that extreme precipitation events (*i.e.*, number of days with precipitation >2.5 cm) will likely increase, and that the length of time between precipitation events will increase (Mote et al. 2014; Easterling et al. 2017).

Risk assessment

Level 3

A risk-based approach to climate change vulnerability assessments provides a common framework to evaluate potential climate change effects and identify a structured way to choose among adaptation actions or actions to mitigate climate change risks (EPA 2014). Risk assessment is linked with risk management by (1) identifying risks—that is, how climate change may prevent an agency or other entity from reaching its goals; (2) analyzing the potential magnitude of consequences and likelihood for each risk; (3) selecting a set of risk-reducing actions to implement; and (4) prioritizing those actions that address risks with the highest likelihood and magnitude of consequences (EPA 2014).

Here, we summarized potential risks that are relevant for natural resource management associated with climate–fire interactions, including: wildfire frequency, extent, and severity; reburns; stress interactions; and regeneration for (1) moist coniferous forest (low to mid elevation), (2) dry coniferous forest and woodland (low to mid elevation), and (3) subalpine coniferous forest and woodland (high elevation). The likelihood and magnitude of consequences, and confidence in inferences are described for each risk. Although the information provided here does not constitute risk management, as described in the previous paragraph, this information can be used to inform more site- and resource-specific risk assessments and risk management.

The risks identified here were inferred from the authors' review of the published literature described below, as well as experience with developing climate change vulnerability assessments in the study region over the past decade (Halofsky et al. 2011a, b; Raymond et al.

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Table 1 Risk assessment for the effects of fire–climate interactions in moist coniferous forest, low to mid elevation (Olympics, west-side Cascades, northern Idaho, west-side Rocky Mountains, USA), for the mid to late twenty-first century. Likelihood and confidence are rated low, moderate, and high. Low likelihood represents consequences that are unlikely (approximately 0 to 33% probability), moderate likelihood represents consequences that are about as likely as not (approximately 33 to 66% probability), high likelihood represents consequences that are likely to very likely (approximately 66 to 100% probability). Low confidence is characterized by low scientific agreement and limited evidence, whereas high confidence is characterized by high scientific agreement and robust evidence, with moderate confidence falling between those two extremes

Fire–climate interaction	Magnitude of consequences	Likelihood of consequences	Confidence
Wildfire frequency	Small increase	Low	High
Wildfire extent	Small increase	Low	Moderate
Wildfire severity	No change to small increase	Low	Moderate
Reburns	No change to small increase	Low	Moderate
Stress interactions	Small increase	Low to moderate	Moderate
Regeneration	No change to small decrease	Low	Low

Franco) and western hemlock (*Tsuga heterophylla* [Raf.] Sarg.). Moist coniferous forests are characterized by an infrequent, stand-replacing (*i.e.*, high-severity) fire regime (Agee 1993). Although fire frequency and severity may increase with climate change, the frequency of fire in these moist ecosystems will likely remain relatively low.

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Risk in dry coniferous forests

Climate–fire risks in dry coniferous forests and woodlands are high for increased fire frequency, extent, and severity (Table 2). Dry coniferous forests and woodlands occur at lower elevations in southwestern Oregon, east of the Cascade Range in Oregon and Washington, and at lower elevations in the Rocky Mountains in Idaho and Montana. Fire regimes in these forests and woodlands range from moderate frequency and mixed severity to frequent and low severity. Ponderosa pine (*Pinus ponderosa* Douglas ex P. Lawson & C. Lawson) is a characteristic species, along with Douglas-fir, grand fir (*Abies grandis* [Douglas ex D. Don] Lindl.), and white fir (*Abies concolor* [Gordon & Glend.] Lindl. ex Hildebr.). These forests and woodlands are also at risk from interacting disturbances and hydrologic change (moderate to high likelihood and magnitude of consequences), and post-fire regeneration failures are likely to occur on some sites.

Risk in high-elevation forests

Climate–fire risks in high-elevation forests are moderate, with a primary factor being increased fire frequency and extent in lower-elevation forests spreading to higher-elevation systems (Table 3). Regeneration could be challenging in locations where seed availability is low due to very large fires. High-elevation forests occur in mountainous areas across the Northwest. They are characterized by species such as subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.), mountain hemlock (*Tsuga mertensiana* [Bong.] Carrière), and lodgepole pine (*Pinus contorta* var. *contorta* Engelm. ex S. Watson). High-elevation forests are characterized by infrequent, stand-replacement fire regimes (Agee 1993). Risks of stress interactions are also moderate, because drought and insect outbreaks will likely affect high-elevation forests with increasing frequency.

Historical and contemporary fire–climate relationships

Paleoclimate and fire data

Wildfire-derived charcoal deposited in lake sediments can be used to identify individual fire events and to estimate fire frequency over hundreds to thousands of years (Itter et al. 2017). In combination with sediment pollen records, charcoal records help to determine how vegetation and fire frequency and severity shifted with climatic variability in the past (Gavin et al. 2007). Existing paleoecological reconstructions of the Northwest are based mostly on pollen and charcoal records from lakes in forested areas west of the Cascade Range, with few studies in the dry interior of the region (Kerns et al. 2017).

The early Holocene (*circa* 10 500 to 5000 years BP) was the warmest post-glacial period in the Northwest (Whitlock 1992). During the early Holocene, summers were warmer and drier relative to recent historical conditions, with more intense droughts (Whitlock 1992; Briles et al. 2005). In many parts of the Northwest, these warmer and drier summer conditions were associated with higher fire frequency (Whitlock 1992; Walsh et al. 2008; Walsh et al. 2015).

Sediment charcoal analysis documented relatively frequent (across the paleoecological record) fire activity during the early Holocene in eight locations: North Cascade Range (Prichard et al. 2009), Olympic Peninsula (Gavin et al. 2013), Puget Lowlands (Crausbay et al. 2017), southwestern Washington (Walsh et al. 2008), Oregon Coast Range (Long et al. 1998), Willamette Valley (Walsh et al. 2010), Siskiyou Mountains (Briles

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Authors' contributions

JH led the study and contributed to information collection, analysis, and interpretation, and co-wrote the paper. DP contributed to information collection, analysis, and interpretation, and co-wrote the paper. BH contributed to information collection, analysis, and interpretation, and co-wrote the paper. All authors read and approved the final manuscript.

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Availability of data and materials

Please contact the corresponding author for data requests.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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