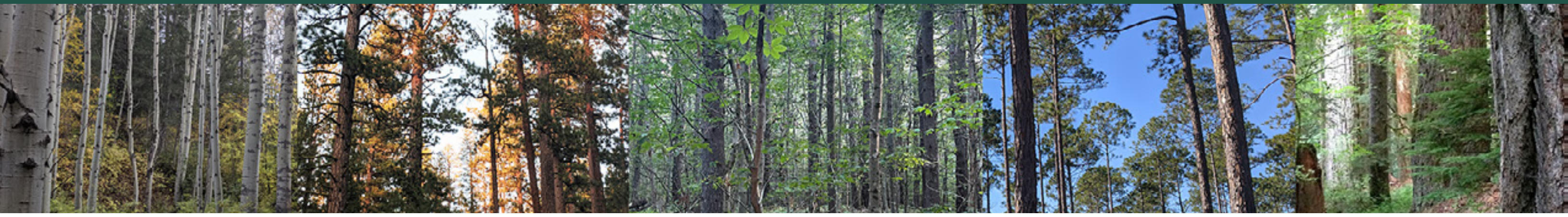

Braiding Indigenous and Western Knowledge for Climate-Adapted Forests:

An Ecocultural State of Science Report

MARCH 2024

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This report was designed by Gina Cova.

WHO WE ARE

We are an intercultural, interdisciplinary team of Indigenous and Western scholars and practitioners. We emphasize place-based strategies for adapting North American forest landscapes to climate change and wildfire. As we collaborate to restore resilience to forest landscapes for future generations, we believe it is essential to respectfully acknowledge the vital and longstanding role of humans working within ecosystems to ensure their sustainability.

ACKNOWLEDGMENTS

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EXECUTIVE SUMMARY

THE PROBLEM

North American forests are experiencing unprecedented challenges due to extreme wildfires, pathogen and insect outbreaks, heat stress, drought, rapid development, and invasive species. Exacerbated by climate change, these threats collectively diminish cultural values, economic values, and habitat. Contemporary and historical management, including a long legacy of fire exclusion in many sites, are root causes of current forest conditions.

Our ecocultural state-of-knowledge report brings together Indigenous Knowledge (IK) and Western Science (WS) to support climate and wildfire adaptation strategies for forest landscapes. This report builds on federal directives to respectfully and intentionally braid IK and WS knowledge systems in a *Two-Eyed Seeing* approach that informs climate- and wildfire-adaptation strategies to conserve our public forests (Kimmerer & Lake 2001; Kimmerer 2013; Reid et al. 2020). Our writing team's cultural, geographic, and disciplinary diversity enables us to provide guidance that can enhance forest resilience and sustainability for future generations. We provide five recommendations to address current challenges to our nation's forests.

Indigenous Peoples stewarded lands throughout North America (NA) for millennia. Forest landscapes maintained with continuous active burning contained diverse, multi-aged communities, including coniferous and hardwood forests and shifting mosaics of non-forests, such as meadows, shrublands, riparian areas, wetlands, and sparsely treed woodlands. Indigenous stewardship based on reciprocity[1] shaped these ecological and cultural (hereinafter, *ecocultural*) systems and the values they provided. Today's forests continue to require respectful, proactive stewardship that fosters economic and ecological values such as clean water, fertile soil, food, material resources, and stored carbon.

Many forest landscapes face escalating damage and loss due to increasingly frequent, severe, and extensive wildfires, and pathogen and insect outbreaks. These threats warrant changes in forest stewardship and related policy. Historical and contemporary forest management unintentionally contributed to these conditions by focusing on economic benefit from forest products and short-term solutions (e.g., fire suppression, disaster response) at the expense of proactive investments in management. Because of conservation strategies such as sustained-yield policies, many US forests currently store more carbon than in the 19th century. However, without proactive stewardship, a substantial portion of that carbon is being suddenly reduced under climate change and wildfires (DeLuca & Hatten 2024).

Compounding losses call for braiding together diverse worldviews to create complementary changes to forest management that address the scale and urgency of current needs. Given widespread departures from historical conditions and anthropogenic climate change, we cannot restore conditions to mirror the past. Instead, we can reinstate ecocultural practices that restore historical forest dynamics and climate resilience. Braiding IK and WS to inform an adaptive brand of stewardship offers the best chance of conserving forest landscapes for future generations, while addressing ongoing threats and losses (Kimmerer 2013).

As we consider the importance of future forests, we acknowledge the influential past, present, and future role of Indigenous Peoples and their IK in shaping forest ecosystems. We recognize that a vast body of WS supports restoring climate-resilient forest structure and processes, including understory composition and biodiversity. Where disturbances were historically frequent, as in many seasonally dry NA forests, cultural burning, prescribed fire, forest thinning, meadow, woodland, and hardwood forest restoration, and fuel reduction can support climate adaptation.

VISIT OUR PROJECT WEBSITE:
adaptiveforeststewardship.org

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adaptiveforeststewardship.org/map

1 Taking from the land with the moral responsibility of giving back in equal measure.

We offer the following recommendations to restore resilience to our nation's forests:

1. Adopt proactive stewardship. In historically frequent-fire forests, invest broadly and intentionally in cultural and prescribed burning, forest thinning, and other active forest management at the pace and scale needed to overtake the influence of modern novel wildfires, restore resilience, and reduce reliance on fire suppression and disaster response.

2. Recognize and respect Tribal Sovereignty and Indigenous Knowledge. Establish and support Government-to-Government co-stewardship partnerships with Tribal Nations at all stages of policy development, planning, monitoring, decision-making, and adaptive stewardship.

3. Provide the flexibility to steward dynamic landscapes and navigate uncertainties under rapidly changing conditions. Managing for static landscape conditions has been ineffective with respect to changing disturbance. Especially under climate change, high-severity fire, drought, and insect disturbances cannot be prevented in areas prioritized for mature and old-growth forest conservation. All landscapes, even designated reserves, are dynamic.

4. Ground agency planning, and land and resource stewardship policies in ethics of reciprocity and responsibility to many future human generations. Through active reciprocal stewardship, people benefit from and provide for the ecosystems that support them for generations.

5. Catalyze innovative approaches to forest stewardship. Effectively fund adaptive, long-term, forest stewardship, and long-term monitoring at stand-to-landscape scales across all partnerships. Learning what works best as conditions change to inform modification of best practices lies at the heart of adaptive reciprocal stewardship.

Tree illustration: Bob Van Pelt / Braided sweetgrass illustration (cover): Jessie Thoreson / Cover page photo credits: Top panel - Susan Prichard; Bottom panel (left to right) - Burns Lake Community Forest / British Columbia Community Forest Association; Courtney Peterson, CSU; Jessica Raspitha, Saint Regis Mohawk Tribe; Susan Prichard; USFS.

PART I: KEY TOPICS

INFORMING FOREST CLIMATE ADAPTATION WITH TWO-EYED SEEING

IN A NUTSHELL: Guided by Indigenous Knowledge (IK) and Western Science (WS), we recommend proactive, place-based co-stewardship of dynamic forest landscapes as the fundamental approach to helping them adapt to climate change and wildfires. Such stewardship provides the means for conserving old and other forests for future generations of people and native species.

In April 2022, to address the unrivaled harms caused by climate change, modern, novel wildfires, past forest management, and associated steep declines in the condition of many United States (US) forests, President Biden signed Executive Order 14072, *Strengthening the Nation's Forests, Communities, and Local Economies.*[2] EO 14072 called for conserving and safeguarding old and mature forests, and initiated an unparalleled inventory and threat assessment of their conditions across all US federal lands. It called for climate-smart, forward-looking planning, management, and conservation strategies for these forests. In response, we produced this state-of-knowledge analysis of the problem and solutions.

Based on the geographic diversity of forests and the floral, faunal, and human communities that live within them, we share understanding, strategies, and actionable examples of adaptive stewardship that blends knowledge across cultures. We highlight ongoing threats and climate-adaptation strategies specific to NA boreal and hemi-boreal forests,[3] and eastern and western temperate forests.

Our report builds on EO 14072 directives to braid Indigenous and Western Knowledge systems in a Two-Eyed Seeing approach (Bartlett et al. 2012) to respectfully and directly inform federal land management, per guidance from the USDA Forest Service (FS) Office of Tribal Relations (OTR) in their *Strengthening Tribal Consultation and Nation-to-Nation Relationships FS Action Plan* of January 2023.[4]

IK (the term preferred by Tribal Nations, which encompasses Traditional Ecological Knowledge and Indigenous Ecological Knowledge) represents the deep systemic body of knowledge and cultural practices passed from generation to generation since time immemorial. It is informed by cultural practices and memories, an innate sensitivity to and ongoing awareness of change, and values that include reciprocity (Kimmerer & Lake 2001). As defined by the OTR and the White House Office of Science and Technology Policy (OSTP) Council on Environmental Quality (CEQ), IK is a body of observations, oral and written knowledge, innovations, practices, and beliefs developed by Tribal Nations and Indigenous Peoples through interaction and lived experience with the environment. Because each Indigenous community has a unique culture, definitions and terminology may vary among them. IK can be developed over millennia, continually evolves, and includes understanding based on evidence acquired through direct contact with the environment and long-term experiences, as well as extensive observations, lessons, and skills passed from generation to generation. In the US, IK is developed by Indigenous Peoples including, but not limited to, Tribal Nations, Native Americans, Alaska Natives, and Native Hawaiians.[5]

Fundamental characteristics of IK observations are that they are both qualitative and quantitative. IK observations are diachronic (long-term), often made by persons who hunt, fish, and gather for subsistence and to support lifeways. Most importantly, IK is inseparable from a culture's spiritual and social fabric, offering irreplaceable ecological and cultural knowledge that can span dozens of human generations.

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2 Strengthening the Nation's Forests, Communities, and Local Economies—EO 14072. https://www.federalregister.gov/documents/2022/04/27/2022-09138/strengthening-the-nations-forests-communities-and-local-economies

3 Hemi-boreal forests are those occurring latitudinally between temperate and boreal ecosystems.

4 Strengthening Tribal Consultation and Nation-to-Nation Relationships USDA Forest Service Action Plan 2023 https://www.fs.usda.gov/sites/default/files/fs_media/fs_document/Strengthening-Tribal-Relations.pdf

5 OSTP CEQ 2022 Guidance for federal departments and agencies on Indigenous Knowledge. https://www.whitehouse.gov/wp-content/uploads/2022/12/OSTP-CEQ-IK-Guidance.pdf

KEY TERMS

We offer the following definitions to suggest common language that informs policy by respectfully braiding IK and WS.

RECIPROCITY is both fundamental awareness and action in response to awareness that humans and ecosystems have shared needs. It involves attention to mutually beneficial relationships between stewards and the land, plants, and animals they live among and rely on. In reciprocal culture, people have strong connection to a place and a moral responsibility to care for that place and its living beings.

PLACE-BASED RECIPROCAL STEWARDSHIP is an ethical value that grounds planning and management practice and applies that value to place-based stewardship of nature, the economy, health, cultural resources, property, and information. Indigenous Peoples and their cultural practices exemplify place-based reciprocal stewardship. Their approach emphasizes learning by doing and local connection of people to the places that sustain them and are sustained by them. Practices include intentional burning, forest thinning, other fuel reduction treatments, pest and postfire management, and seed collecting of native species to assist forest community regeneration.

ECOCULTURAL RESTORATION is the process of restoring climate- and wildfire-adapted ecosystem structure, composition, and processes, and the Indigenous cultural practices that helped shape them over deep time. Braiding together WS with IK restores the practice of place-based stewardship and reconnecting people to place. IK will need to be applied in a way that recognizes current distorted, novel conditions created by a century of western management, fire suppression, and cessation of management.

CO-STEWARDSHIP, in the US, refers to a broad range of working relationships between the federal government and Indigenous Peoples exercising the delegated authority of federally recognized Tribes. Co-stewardship can include co-management, collaborative and cooperative management, and Tribally led stewardship, and can be implemented through cooperative agreements, memoranda of understanding, self-governance agreements, and other mechanisms.

CO-MANAGEMENT describes arrangements to manage natural resources with shared authority and responsibility. While treaty rights, legislation and other legal mechanisms have fostered such arrangements, co-management is more generally the result of extensive deliberation and negotiation to jointly make decisions and solve problems.

Moral values, such as kinship with nature, humility, and reciprocity, are foundational to IK systems. IK-informed stewardship often includes cultural burning and adjusting timber and other plant harvest methods and timing to create more sustainable communities of culturally significant traditional plants that provide wildlife habitat, and in turn, food, medicines, and material resources for humans (Kimmerer 2011; Lake et al. 2017, 2018).

This contrasts with WS, an empirical inquiry system shaped by binary logic, dualism, and mechanistic hypothesis testing. Core aspirations of WS are singularity of truth (monism) and objectivity. WS often features synchronic (short-term, at a place, and within a specific time period) studies that strive to be value-free (unbiased, amoral). WS research ideally includes systematic, replicated experimentation, accurate measurements, and empirical tests, which can lead to generalizable statistical models that have WS credibility and legitimacy. However, some WS studies are diachronic (e.g., paleoecological studies, long-term ecological research).

A broad wealth of knowledge not often found in synchronic observation is present in diachronic work, owing to insights derived over the broad sweep of time by Indigenous Peoples, where comparisons of differing conditions and their contexts are retained and used. As such, IK is a key source of best-available scientific information, and a valid and important form of evidence for inclusion in federal policy, research, and decision-making. IK and WS knowledge do not depend on each other for validation, and each system can support the insights of the other.[6]

IK and WS knowledge systems represent two very different worldviews. IK involves humans seeing themselves as embedded in nature, in relationship with the landscape and its parts. In the Indigenous worldview, humans approach the natural world with humility, and see themselves as here, on this Earth, to learn from and care for nature with reciprocity, a core value of IK. People respectfully take from nature, with the moral responsibility of giving back in equal measure.

Two-Eyed Seeing combines the insights and deep wisdom of IK and the empirical strengths and logic of WS to gain binocular vision that enables people to develop broad-minded solutions to challenging ecosystem problems (Bartlett 2012). Reid et al. (2020) proposed a circular framework for intercultural partnerships with Indigenous Peoples, to address co-management of fisheries in Canada. We modified that framework to be more applicable to US policies for partnering with Tribal Nations in co-stewardship and working with IK in forested landscapes (Figure 1). The cycle begins by identifying shared priorities and mutual benefits of co-stewardship, co-creating stewardship plans, co-creating methodology, implementing co-stewardship, and co-evaluation, and community validation. This results in shared recognition of the value of co-stewardship and its mutual benefits, which can grow and strengthen long-term relationships between all involved. The cycle repeats as one restores resiliency and native species, for example, to a forest where Indigenous burning has been excluded for nearly two centuries. It aligns well with recent federal policies such as Presidential Executive Order 14112, *Reforming Federal Funding and Support for Tribal Nations*.[7]

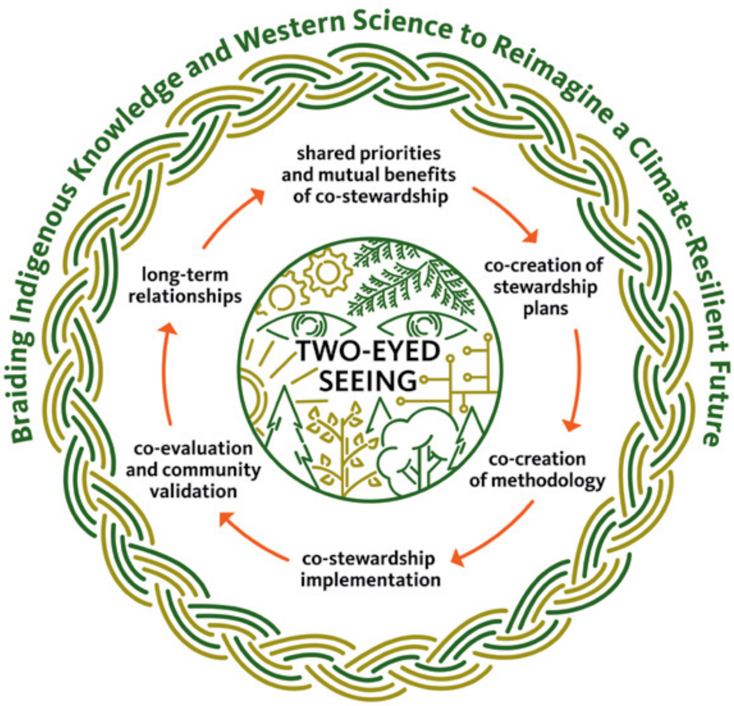

Figure 1: Two-Eyed Seeing: An adaptive co-stewardship model. Credit Cristina Eisenberg, Oregon State University College of Forestry.

BRAIDING SWEETGRASS FOR DIVERSITY, INCLUSION, AND FOREST RESTORATION

IN A NUTSHELL: We discuss our diverse writing team's need to present broad perspectives, deep intellectual, spiritual, and philosophical concepts, knowledge systems, traditions, cultural practices, and experiential learning. We apply this collective mindset to appraise current threats and conditions and to recommend ways forward that intentionally and respectfully braid IK and WS.

In her book *Braiding Sweetgrass: Indigenous Wisdom, Scientific Knowledge, and the Teachings of Plants*, Dr. Robin Wall Kimmerer describes the craft of

6 Federal Register Volume 88, No. 243, December 20, 2023. USDA Forest Service. Land Management Plan Direction for Old-Growth Forest Conditions across the National Forest System. Notice of Intent to prepare an Environmental Impact Statement. https://www.govinfo.gov/content/pkg/FR-2023-12-20/pdf/2023-27875.pdf

7 EO 13646, Dec. 2023, https://www.whitehouse.gov/briefing-room/presidential-actions/2023/12/06/executive-order-on-reforming-federal-funding-and-support-for-tribal-nations-to-better-embrace-our-trust-responsibilities-and-promote-the-next-era-of-tribal-self-determination/

braiding sweetgrass as rooted in strong community. It requires many hands to tend sweetgrass, harvest it respectfully, and then braid it. The choice of grass blades and the collection site are as important as the careful weaving of the braid. While each blade is fragile on its own, when braided together, the strands are highly resilient (Kimmerer 2013).

Our writing team comes from diverse cultural, geographic, and disciplinary backgrounds. As a team, we are symbolically braiding sweetgrass as we think and write. According to Kimmerer, the three braided strands represent the intertwining of IK, WS, and Spirit. In the context of this report, we define Spirit as our collective connection to forest communities and our mutual grave concern about their vulnerability to climate change and related stressors. Wildfire extent and severity is increasing across western NA forests as warmer, drier summers challenge tree regeneration and establishment (Coop et al. 2020). Nonnative and native insects and pathogens threaten mature and old trees in many dense contemporary forests. Composed of drought-sensitive species established during fire exclusion, these forests are maladapted to increasing drought stress (Hagmann et al. 2021). Addressing these threats warrants changes to forest stewardship and policy.

Collectively, our writing team envisions a future in which best-available IK and WS guide sustainable adaptive forest stewardship. Prior to settler colonization, Indigenous stewardship broadly shaped forest landscapes and the many values they provide (Hoagland 2017). Under active stewardship and ongoing disturbances, forest landscapes retained diverse communities, including multi-aged trees, which existed within dynamic mosaics of meadows, shrublands, riparian areas, wetlands, and woodlands.

Indigenous Peoples' view of nature includes a duty to sustainability that considers impacts on future generations. The Haudenosaunee call this the *Seventh Generation Principle* (Clarkson et al. 1992). Today's forests continue to require respectful, proactive stewardship that fosters values such as clean water, fertile soil, food, material resources, and carbon storage.

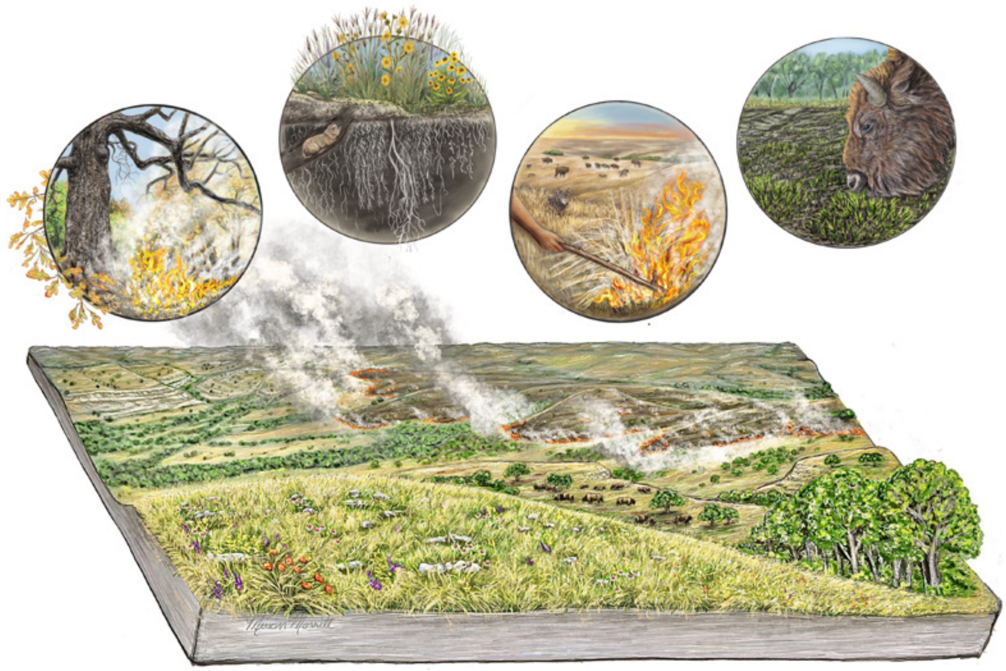

Figure 2. A strong body of WS evidence supports restoring climate-resilient forest structure and processes, including understory composition and biodiversity, through cultural and prescribed burning, forest thinning, ecocultural restoration, and hazardous fuel reduction. Illustration by Miriam Morrill.

A strong body of WS evidence supports restoring climate-resilient forest structure and processes, including understory composition and biodiversity, through cultural and prescribed burning, forest thinning, ecocultural restoration, and hazardous fuel reduction (Figure 2, Kalies and Kent 2016; Jain et al. 2021; Prichard et al. 2021). Similarly, fire- and drought-tolerant tree species can be restored as the structural backbone of old forests (Dey 2014; Falk et al. 2019; Stephens et al. 2020). These important biological legacies are highly stable and can keep forest ecosystems intact.

The disciplines of forest ecology and management have matured over the past decades, both acquiring a much greater understanding of the interconnectedness of forests with water, carbon cycles, plants and animals, habitats, and human communities. Strong WS evidence also underscores the importance and irrepressible dynamism of forest landscapes and the role of disturbances in shaping patterns, composition, and ecological memory (Falk et al. 2022; Hessburg et al. 2019; Peterson 2002).

Considering outcomes of the 19th and 20th centuries and the complex problems humanity faces today, it may be difficult to imagine humans as other than extractive or destructive. Knowledge systems associated with application of IK offer a vastly different perspective—one that created sustainable, dynamic, resilient ecosystems over millennia. Forest landscapes co-evolved with people living and working within them. Intentional human interactions with landscapes and fire broadly shaped forests and their rich species diversity, and will shape future forests. While recommending increased flexibility in forest and land management, we are also recommending placing guardrails on this flexibility or otherwise ensuring extractive and destructive forces are not repeated. Issues of trust necessitate monitoring to verify that human interactions with forests bear intended fruit. Such monitoring is also central to WS learning and IK adaptive stewardship.

A BRIEF HISTORY OF COLONIZATION

IN A NUTSHELL: We summarize the history of Euro-American colonization to contextualize current conditions, causes, and consequences, as well as potential paths forward.

In what is today the US, Euro-American colonizers took land from Indigenous Peoples indirectly through introduction of diseases, and directly through violence, broken treaties, genocide, and forced removal to reservations. Settler colonialism involved modernizing and/or destroying Indigenous Peoples and their cultures by force (Veracini 2011). Such beliefs were rooted in the *Doctrine of Discovery*,[8] a 15th century Papal order used to justify Columbus' settlement of the "new world" via genocide and forced assimilation (Wilkins & Lomawaima 2002, Dunbar-Ortiz 2021).

There were many impacts of colonization. Among the most damaging was genocide; 80-90% of the Indigenous population perished in waves of introduced European and African diseases. Additional deaths resulted from warfare and indiscriminate killing of women and children over the course of settlement. Later impacts included widespread loss of ancestral lands through settler colonization (e.g., stealing and development), and oppression by criminalization (often punishable by death) for performing traditional cultural practices (e.g., hunting, burning, ceremonies, and occupation of usual and accustomed gathering and spiritually important places). Relocation and forced removal to boarding schools led to additional loss of languages, cultures, and traditions (Daschuk 2019, Treuer 2019). In the US, settler colonialism forcibly took the most productive forest lands from Indigenous Peoples, despite scores of signed treaties with the US government guaranteeing their right to those lands. Settler colonialism resulted in the passing of the 1862 and 1890 Morrill Acts, with the explicit goal of eliminating Indigenous societies (Wilkins & Lomawaima 2002).

Decolonization then is the reversal of losses to language, culture, beliefs, and resource practices, and restored access to ancestral homelands. It leads to the elimination of pernicious institutional structures, ecosystem degradation, and healing of the deep transgenerational trauma to Indigenous Peoples created during colonization and its aftermath. We live in a settler-colonial world in which all systems (federal governance structure, federal and state agencies and laws, institutions of higher education, markets and policies) are reflections of settler-colonial practices. Decolonization requires that we respect and incorporate multiple ways of knowing. When applied to increase US forest climate and wildfire resilience, decolonization entails a paradigm shift in how we think about *all* forests, not just old and mature forests, and how we re-establish the central role of humans in nature.

HOW SETTLER COLONIALISM CHANGED NORTH AMERICAN FORESTS

IN A NUTSHELL: We briefly summarize the primary effects of Euro-American settlement and colonization on North American landscapes.

As a consequence of introduced disease, Europeans arrived on an already settled continent that had recently been depopulated. Many settlers' orthodoxies held that aboriginal peoples and their lifeways were pagan and less than fully human (Williams 1992).

8 Pope Alexander VI 1493. Doctrine of Discovery

NA had been successfully inhabited and settled for millennia by Indigenous Peoples, whose cultural burning practices had shaped the landscape. In the early stages of Euro-American settlement, rapid changes in forest ecosystems occurred through initial land clearing and burning for agriculture (Figure 3). As colonization continued, federal policies of forced removal, displacement, and genocide further reduced the Indigenous population (Heart & DeBruyn 1998). In many places, a period of fire exclusion spanning 170 years or more followed (Eisenberg et al. 2019). By decimating Indigenous presence, this genocide reinforced the perception of NA as *terra nullius* ("land belonging to nobody") as colonists moved west. Such ideologies still inform modern land conservation and protection and enable ongoing erasure of Indigenous Peoples and their stewardship.

EASTERN NORTH AMERICA

The eastern region of NA suffered the most severe impacts of Euro-American settlement. Indigenous Peoples experienced widespread devastation and depopulation due to the spread of foreign diseases and later through genocide as part of Hernando de Soto's 1539 conquest, and subsequent European expeditions (Clayton et al. 1995; Jones 2014; Van Lear 2005). The survivors widely suffered forced removal from and dispossession of their ancestral lands.

Subsequent African enslavement compounded this enormous human tragedy. The settler economy had become dependent on plantations and enslaved African labor to produce crops. The legacy of African-American cultural and ecological effects and outrageous social justice violations persists today in the southeastern and eastern US.

Human-ignited fire changed dramatically in the East after early colonization with a wave of more frequent fire followed by a steep decline in frequent fire, significantly degrading eastern forests (Margolis et al. 2022; Stambaugh et al. 2018, 2020). It was not until the 18th century that further widespread colonization occurred, displacing more Indigenous Peoples and bringing region-wide landscape change through land clearing, logging, and conversion to other uses (Hämäläinen 2022).

The promise of economic opportunity and freedom from religious persecution in Europe drove a migration wave of 30-40 million settlers (Hatton and Williamson 1992). Some sought escape from famine and poverty as the late blight of potato epidemic was ravaging Europe and Britain, destroying essential crops. Some sought the promise of land ownership. Among the most expansive of all ecosystems in the continental US, grassland and prairie landscapes were swiftly converted to agriculture (Figure 4). This led to widespread soil degradation, erosion, loss of biodiversity, and the Dust Bowl era (Cook et al. 2009). Additional land was deforested for settlements and eventual urbanization. Widely distributed rural communities provided food for urban centers. A tremendous amount of forestland was lost due to settlement and agriculture. Remaining forest landscapes were further degraded through fire

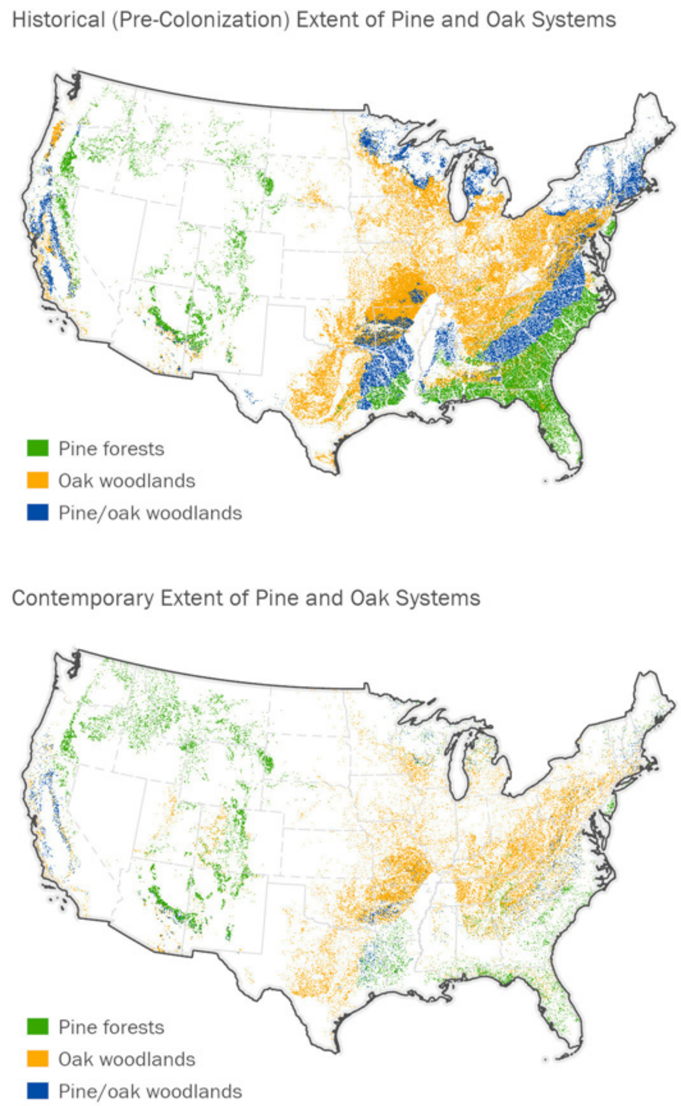

Figure 3. Differences in historical (top) and contemporary (bottom) distributions of oak and pine forests across the US underscore how common fire-adapted ecosystems were prior to Euro-American colonization and their marked subsequent decline and the related decline in frequent burning. Data sourced from LANDFIRE biophysical settings (top) and existing vegetation types (bottom) datasets.

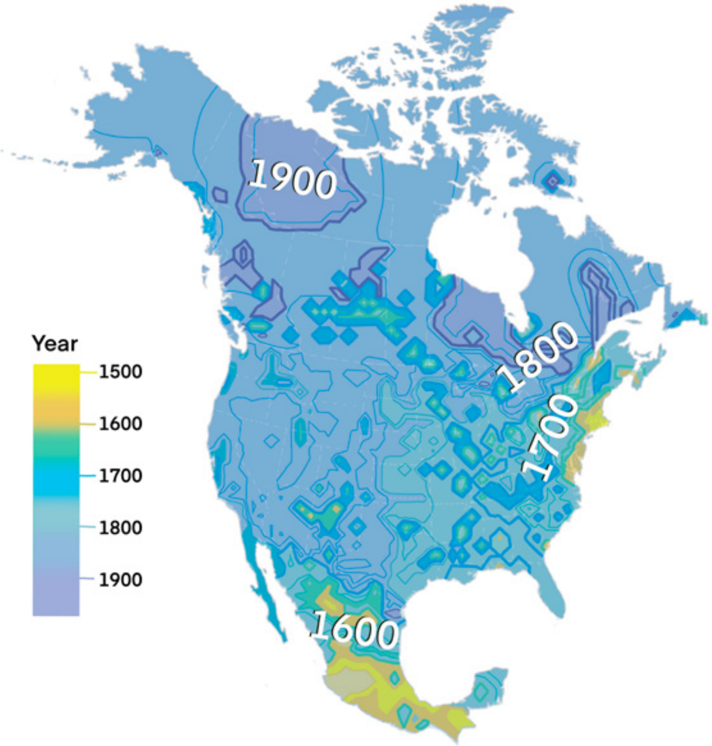

Figure 4. Map depicting the year of land use transitions with possible influenes of fire regimes linked to the NA tree-ring fire-scar network. Figure adapted from Margolis et al. 2022 by Jessie Thoreson.

exclusion and nonnative species introduction (Belsky et al. 1997, 1999; Hessburg & Agee 2003; Landers et al. 1995).

Fire-scar records recorded in the tree rings of pine, oak, and other species extend back to the 1500s within remnant old trees, stumps, and standing snags (Margolis et al. 2022), and in logs and timbers of old buildings and mines. By cross-dating with master chronologies (e.g., Swetnam et al. 1999), the precise year and seasonality of historical fires can be used to characterize historical fire frequency, fire effects on ecosystems, and Indigenous fire stewardship. To date, disruptions to fire regimes have been reconstructed for parts of Appalachia and the central Atlantic states, referred to as the “wave of fire” in eastern NA landscapes (Abrams et al. 2022; Stambaugh et al. 2018). Pre-contact fire records generally demonstrate frequent fires (a 2-10 year fire return interval) that maintained open oak and pine forests, where recording live and dead trees still exist. Most occurred outside of lightning season, strongly tied to Indigenous cultural burning (Marschall et al. 2022; Stambaugh et al. 2018, 2020).

Following Euro-American settlement, fires often became more frequent and extensive, reflecting land clearing and burning. Sharply reduced fire frequency and fire exclusion followed clearing. In pine and oak-dominated forests, this set in motion invasion by mesic understory hardwood species that altered fire environments by making forests denser and shadier, leading to loss of a flammable grass layer and reduction of flammable litter layers. Disruption in Indigenous fire stewardship for windows as short as 30-50 years is linked to increased tree establishment and densification of historically open forests (Nowacki & Abrams 2008).

One of the most apparent impacts of settler colonialism on forests is the widespread loss of the longleaf pine ecosystem, which once spanned an estimated 37 million ha, and is now reduced to < 5% of its former extent. Remaining tracts of old longleaf pine and other forest habitats are fragmented and degraded, due to fire exclusion, hurricane damage, invasive plant species, and additional climate-change related disturbances (Zampieri et al. 2020).

Eastern forests today still host incredible biodiversity—a major source of ecosystem function and overall resilience. However, nonnative insects and pathogens have functionally extirpated or diminished species such as American chestnut, eastern hemlock, ash, and bay (Fei et al. 2019; Lovett et al. 2016). Little is known about how these functional extinctions and extirpations of entire taxa have affected ecosystem function and resilience (Barton & Keeton 2018). Adaptive stewardship and active partnerships with researchers are needed to address major threats to native ecosystems created by nonnative invasive species.

WESTERN NORTH AMERICA

As westward expansion continued with the discovery of gold, silver, and a now more sparsely inhabited landscape, surviving Indigenous Peoples were forcibly removed from their ancestral territories, enslaved, imprisoned, and murdered (Hämäläinen 2022). The devastation of Indigenous ways of knowing, learning, and living was incalculable. Hundreds of traditional societies were impacted, with only remnant populations remaining by the 1850s. In the late 1800s, mass migration of Euro-American settlers into western NA and the related 1870s and 1880s bison slaughter contributed to further genocide and displacement of Indigenous Peoples (Jones et al. 2022). At this time, curtailment and cessation of Indigenous burning practices, coupled with bison extirpation and introduction of livestock herds, contributed to fire reduction (Blesky & Blumenthal 1997; Marlon et al. 2012; Treuer 2019).

Grasses had long been the "conveyor belt" for spreading frequent fires, either human-ignited or lightning-caused, to most interior western NA forest landscapes. Absent grasses, tree seedlings and saplings recruited abundantly, and forests grew dense and layered (Hessburg & Agee 2003, Hessburg et al. 2019). Land development for housing and agriculture further reduced native grassland extent. Although some early settlers intentionally burned grasslands and forest understories to live safely in fire-prone landscapes, Euro-American settlement eventually reduced burning because of its threat to new infrastructure and farming investments (Marlon et al. 2012; Swetnam et al. 2016).

By the early 20th century, roads and railroads crisscrossed the West, acting as fuelbreaks that further inhibited the spread of frequent surface fires (Hessburg et al. 2019). Roads and railroads facilitated access to forestlands and their untapped wood resources. High-grade logging preferentially removed large, old ponderosa and Jeffrey pine, western larch, and Douglas-fir trees from historically fire-maintained forests and savannas. Harvest of large, old trees in the interior West throughout the 19th and 20th centuries removed more than 90% of forests. Meanwhile, smaller, shade-loving, fire-sensitive trees filled in the open spaces left by the removal of large trees, in some cases increasing tree densities 10- to 100-fold relative to pre-colonization times (Hagmann et al. 2021).

Public agencies declared wildfires public enemy number one following the severe destructive fires of the late 1800s and early 1900s, culminating in the Big Burn of 1910 (Egan 2009, Blumm 2011). In 1934 the US Forest Service and its partners began suppressing nearly all fire starts as part of the 10 AM Rule, whereby all fires were to be put out by 10 AM the morning after detection (Pyne 1982). While no longer an overt policy, this practice then shaped and continues to shape modern attitudes and management responses to fire and has had long-lasting cultural and fire-management impacts. Fire suppression effects today are particularly notable across western forest landscapes historically adapted to frequent cultural burning and lightning-ignited fires.

Collectively, these change-agents have transformed many western NA forests and eliminated long-established, reciprocal relationships between traditional societies and their surrounding landscapes. In many places, following the loss of cultural burning and wildfires, forests are now much denser, heavily stocked with shade-tolerant fire-sensitive trees, with densely layered sub-canopies (Figure 5).

Figure 5. Densely stocked stand after a prolonged period of fire exclusion. Methow Valley, Washington. Photo by Susan Prichard.

Within a fairly brief timespan, major changes occurred in western NA, leaving forests many think of as natural and normal, but that are actually profoundly departed from historical conditions (Hessburg et al. 2019). Burned and recovering patchworks of cold and moist forest gave way to a continuous blanket of trees (Figure 5). Many areas once occupied by wet or dry meadows, tall- or short-grass prairies, shrublands, chaparral, and sparsely treed hardwood and conifer woodlands are now either forested or being encroached on by trees (Hagedorn & Flower 2021; Hessburg et al. 2019; Perry et al. 2011). Additionally, areas of quaking aspen and other hardwoods that historically served as barriers to the flow of many severe fires in moist and cold mixed-conifer forests have given way to dense, fire-susceptible conifer forests, often under the influence of silvicide (tree-killing herbicide) treatments (Perala 1985; Sutton 1978).

In following sections, we highlight areas in which weaving IK and WS perspectives can offer broader working definitions of old-growth forests, ecosystem services, wilderness, and forest carbon stewardship.

DEFINING OLD-GROWTH FOREST

IN A NUTSHELL: We discuss the origins of old forests and old ecosystems of varied forest types. We discuss the modern construct of old growth and the lack of this construct in IK or Indigenous forest stewardship. We challenge the modern idea of old forests as pristine, without human intervention, and discuss how old forests emerge from and depend upon the succession and disturbance dynamics of large landscapes within climatic and wildfire regimes.

Many old forest definitions exist, including that used in the recent inventory of old and mature forests of the US (USDA Forest Service 1989). The inventory references a 1989 definition from the Northwest Forest Plan (NWFP), which established a set of late-successional reserves throughout the Pacific Northwest (PNW) region to protect and enhance old-growth forests, which were defined as:

> *. . . dynamic systems distinguished by old trees and related structural attributes. Old growth encompasses the later stages of stand development that typically differ from earlier stages in a variety of characteristics, which may include tree size, accumulations of large dead woody material, number of canopy layers, species composition, and ecosystem function* (USDA Forest Service 1989).

Within the first-ever inventory of old-growth forests in the US, unifying definitions of *old growth* were challenging to create, given the diversity of forest types, changing fire regimes, and other disturbances (Gray et al. 2023; Pelz et al. 2023).

Structural definitions of old-growth forest such as those in the NWFP work well for forests characterized by historically infrequent disturbance regimes. They are less suited to describe old forests that exist within the seasonally dry landscapes that dominated much of NA for millennia prior to Euro-American settlement (Gaines et al. 2022; Spies et al. 2019). The vast historical extent of longleaf pine ecosystems, oak and pine woodlands, and dry and moist mixed-conifer forests contained many frequent-fire ecosystems. Indigenous Peoples set many of these fires. In these culturally fire-maintained landscapes, old trees and patches of old forests developed and persisted within dynamic, and often highly diverse assemblages of open forests, woodlands, grasslands, and shrublands. An emergent property of dynamic ecocultural landscapes, old trees and their diverse understory plant communities are not only adapted to frequent fire across NA, they *depend* on it.

While individual old trees and their related structural attributes are often the focus of old-growth definitions, we suggest that the real entities of concern are *old ecosystems*. Old ecosystems provide a range of physical and informational legacies (Johnstone et al. 2016) that far predate the lifespan of even long-lived trees. These legacies include deep, complex soil and charcoal layers and species assemblages reflecting long-term dynamic processes and influences, such as the ebb and flow of disturbance and climatic regimes (DeLuca & Hatten 2024; Hoffman et al. 2016).

These legacies constitute a long-term ecological memory that reflects not only past evolution, but also ongoing ability to adapt to changes. For example, fire-maintained old forests are often not dense and layered with downed wood as in the NWFP definition. Instead, they are characterized by open canopy structure, diverse tree sizes, and understory plants that foster low-intensity surface fires (e.g., underburns). These forests are generally resistant to crown fires, drought, and large bark beetle outbreaks. Old forest composition is as important as their structure. Fire-adapted species are favored in forests with active fire regimes and open canopies.

The concept of old-growth forests is a Western construct. Indigenous Peoples view forests as structured similarly to human communities, with a diversity of ages, representing a millennial legacy of cultural development and adaptation. According to Indigenous scholar Victoria Yazzie (2007):

> *While [t]he perception of old growth was developed by the non-Indian community…[o]ld growth can be described…as "grandfather" trees. However, old growth goes far beyond the physical appearance of older-aged trees that have specific diameter caps. Old growth can be associated with a combination of grandfather trees with an understory of multi cohort recruitment trees to replace the aging grandfathers.*

Across NA, some of today's old-growth forest definitions, including those in the Mature and Old Growth Inventory (USDA Forest Service 2023) evoke Pacific Coastal forests, with their complex, multi-layered canopies and moss-draped understories filled with vine maple, nurse logs, and regenerating trees. These structurally complex forests are revered not only for their majestic beauty, but also their age. Individual

Douglas-fir can live 800 – 1,200 years, western redcedar can live even longer, and coast redwood are aptly named *Sequoia sempervirens* or “ever living” in Latin. Old-growth forests are sometimes called “ancient forests,” based on their long lifespans and the long intervals between stand-replacement events, such as fires or severe windstorms. Profoundly fragmented and modified today (Yazzie 2007), forests with comparable antiquity and similar complex structure exist throughout the US, including relict Appalachian old-growth eastern hemlock and bald cypress stands (Barton & Keeton 2018). Although old forests with closed canopies, multi-layered structure, and abundant coarse wood do exist and represent this structural definition, widespread application of this archetypal definition is problematic (Hagmann et al. 2021; Hessburg et al. 2016, 2019).

Western culture has also depicted old-growth forests as existing historically as pristine wilderness without human influence, excluding the role of Indigenous Peoples in maintaining these ecosystems. Indigenous Peoples predated even today’s iconic old-growth Pacific Coast forests by thousands of years. For example, about 6,000 years ago, the prevailing climate shifted to one dominated by cool, moist conditions, with infrequent fires (Brubaker 1991). A cooler, moister climate allowed establishment and growth of shade-tolerant western hemlock and redcedar trees (Sprugel 1991; Whitlock et al. 2003) in the west Cascades, Olympic Mountains, and British Columbia Coast Range. It was not until some of the earliest of these trees became old (ca. 3,500 years BCE), that Indigenous Peoples crafted totems and dugout canoes from western redcedar (Hebda & Mathewes 1984).

Given our national forests’ impressive diversity and the lasting legacy of Indigenous stewardship, conserving them for future generations requires holistic, system-level thinking and understanding the diversity of landscapes and their disturbance regimes (Johnston et al. 2023; Lorimer et al. 2009; Tepley et al. 2013).

ECOSYSTEM SERVICES OR RECIPROCAL RELATIONSHIPS?

IN A NUTSHELL: We discuss the value of forests to people. Are people outside of forests, extracting goods and services that they desire, or are they in reciprocal relationships with forests? We suggest that a purely extractive and reactive approach to forest management is unsustainable, and that a reciprocal stewardship relationship with forests worked for centuries prior to colonization and can work again.

Forests are widely recognized for their diverse values to human communities. Many forest landscapes are critical municipal watersheds, valued for their cold, clean drinking water. Forests provide two-thirds of the US municipal water supply and half of the US population’s drinking water (Liu et al. 2021, 2022). Through photosynthesis, they sequester carbon from CO_2 and release oxygen back to the atmosphere. They store carbon both in above-ground biomass and in soils, and host an incredible diversity of plant and wildlife habitats. They are also used for materials, including a wide range of timber and nontimber products. Collectively or individually, these values in WS parlance are sometimes referred to as *ecosystem services* (Guillermo et al. 2018).

Ecosystem services are generally divided into four basic types: provisioning, regulating, cultural, and supporting services (Churchill 2005). Provisioning services include production of food and water. Regulating services are benefits people obtain from regulating ecosystem processes, such as air quality, climate, erosion, human diseases, and water quality. Cultural services include spiritual, recreational, and other benefits. Supporting services include nutrient cycles and oxygen production. Although language about these values and services may differ, Western and Indigenous perspectives both recognize the important values of forests to people.

As we explore ways to weave together WS and IK, place-based stewardship is an essential component of climate-change adaptation strategies that aid in regulating the Earth’s climate system to a better state. These strategies emphasize the close connection of people to the places that sustain them and are sustained by them. A break in those connections creates a break in sustainable living. Indigenous Peoples and their traditional practices exemplify place-based stewardship, recognizing that ecosystems are in service to people and people are in service to ecosystems.

A culture of reciprocity has both a strong connection of people to places and a moral and ethical responsibility to that place and its living beings. To meet today's multiple challenges to forest landscapes, this ethic of reciprocity and responsibility for future generations is a critical component of climate-change adaptation. Reciprocity can catalyze the pace and scale of adaptation more effectively than narrowly defined objectives, such as wildfire-risk reduction, single-species management, or other ecosystem services.

FOREST CARBON STEWARDSHIP

IN A NUTSHELL: Sustainable forest carbon storage will derive from a deep understanding of the Earth's climate system and the land and ecosystem processes that have influenced and stabilized it over time. We discuss concepts of above-ground and below-ground carbon, and why both matter, carbon stability and instability, their dependence on dynamic forest and nonforest conditions, and their inextricable linkage to long-term forest succession and disturbance.

In NA, some nature-based climate solutions have emphasized expanding aboveground forest carbon stores, and encourage high stocking and biomass of trees growing on any given site. Nature-based climate solutions that simplistically emphasize above-ground carbon sometimes ignore key ecosystem processes and stabilizing feedbacks that can be weakened or eliminated by maximizing tree density and biomass at the expense of biodiversity (DeLuca & Hatten 2024; Ellis et al. 2024).

Many fire-excluded NA forests are already rich in above-ground carbon due to the densification and encroachment of forests and subsequent loss of savannas, meadows, wetlands, and shrublands over the last 170 years or more. In their current state, above-ground carbon stores are unstable due to the risk of burning at high severity, which often results in significant losses to associated live carbon sinks[9] and stocks.[10] In many forests, more than half of the ecosystem carbon is stored below-ground (soil and root carbon, charcoal).[11] While mineral soil carbon is generally quite resilient to wildfire impacts, high-severity fires can result in significant losses of surface soil carbon and related soil biodiversity. Forest resilience depends on this soil biodiversity (DeLuca et al. 2019).

An era of unprecedented fire exclusion in NA has resulted in forested landscapes maladapted to climate change and predisposed to high-severity wildfires. As evidenced by record-setting wildfires in the US and Canada, swaths of forestland, barren land, and tundra are burning, releasing vast quantities of greenhouse gasses to the atmosphere and creating hazardous air quality conditions, with disproportionate impacts to disadvantaged human communities (D'Evelyn et al. 2022; Gao et al. 2023).

Fire suppression can result in higher aboveground carbon stocks (e.g., Foster et al. 2020). However, these carbon stocks are at elevated risk of loss. Reducing risk to carbon stocks requires a more nuanced approach than simply planting trees and maintaining high levels of forest biomass (Prichard et al. 2021). Instead, climate-change adaptation practices to conserve fire- and drought-prone forests include forest thinning and underburning (Hurteau et al. 2019). Post-disturbance activities include reducing stocking of the fire-sensitive tree species that encroached on forests and nonforests during the protracted historical fire-exclusion period (Larson et al. 2022). These strategies will simultaneously reduce forest susceptibility to drought from overstocking and improve tree resistance to native forest insects and pathogens (North et al. 2017, 2022).

Low- and moderate-severity fire, such as occurs in many wildfires, as well as cultural and prescribed burning, can increase belowground carbon over time, by depositing pyrogenic carbon (PyC, or charcoal) in surface soils (Reisser et al. 2016). PyC influences nitrogen cycling and improves soil water-holding capacity and nutrient flow to plants. Adaptive stewardship can help stabilize forest carbon by reducing the likelihood of uncharacteristically large and severe fires that can consume surface soil carbon,

9 An environment (e.g., ocean) or land cover condition that can absorb and retain carbon.

10 An environment or condition where carbon is already stored (e.g., marine organisms, live or dead biomass, soils).

11 A little over half of all forest carbon is stored in roots and charcoal in soil.

including PyC. When forest landscapes are resilient to wildfire, more of the fire that occurs will be of low and moderate severity, as was the case prior to fire exclusion. Cultural and prescribed burning can increase and stabilize soil carbon, which persists for hundreds to thousands of years in an old ecosystem. Maintaining this forest carbon pool has been part of IK for millennia and is important to forward-looking adaptive stewardship (Pellegrini et al. 2021).

Cultural and prescribed burning are generally implemented as low- or moderate-severity fires in forest understories. Such burns produce lower particulate and greenhouse gas emissions compared to wildfires, and facilitate mitigative measures to protect human health (Schollaert et al. 2023). For a time they reduce the likelihood of severe future wildfires. Allowing unplanned wildfires to burn under mild-to-moderate weather conditions can also reduce the size and severity of subsequent wildfires (Parks et al. 2015; Prichard et al. 2017).

However, significant barriers exist to expanding the footprint of prescribed and cultural burning. With so many contemporary fires in summer, downwind populations and fire crews experience fire and smoke fatigue. Agencies are risk-averse to potential escaped burns. Although the majority of prescribed fires go according to plan, escapes have occurred and will continue to occur in rare instances. There is no such thing as a no-risk strategy for returning proactive fire treatments to forests. Yet, proactive fire risks pale in comparison to those of full and aggressive suppression, which creates fires of much higher burn severity, size, and smoke emissions (Calkin et al. 2014, 2015; North et al. 2015). In his 2023 90-day pause memo, the Chief of the FS noted a 99.84% success rate for prescribed fire implementation. In wildlands, changing land use and expanded recreation development have increased managers' liability concerns, complicating prescribed and cultural burning. State and federal air quality regulations pose additional barriers, even though these practices have been proven to mitigate future fire severity, greenhouse gas emissions, and smoke production (Schultz et al. 2019).

ECOCULTURAL SUSTAINABILITY AND CONCEPTS OF RESERVES AND WILDERNESS

IN A NUTSHELL: Modern Western conservation was a response to the seemingly unstoppable forces of development and extraction. This included seeking to protect areas thought to be relatively unimpacted as designated reserve areas (e.g., parks and wilderness areas). However, the value of these areas was often tied to perceptions of them as being long unpeopled; an assumption ignoring both the millennia-long history of Indigenous Peoples' active relationship with these areas and the history of the forced removal of Indigenous Peoples from some of these reserves. Ironically, in the face of climate change, reserve-focused approaches also threaten reserves themselves. We suggest how our thinking about reserves might change to aid progress toward ecocultural sustainability.

By the early-20th century, activities such as rapid development, timber extraction, and the commercial hunting of large game prompted the rise of modern land conservation. A variety of designated reserved areas (hereafter, "reserves") (e.g., parks and wilderness areas) were created to protect remaining lands from development and commercial exploitation. Today, these reserves are highly valued in North America, and play a critical role in forest conservation, especially while the threat of exploitation remains (Dietz et al. 2021; Talty et al. 2020). At the same time, this brand of Western conservation and a focus on reserves came at a cost to Indigenous Peoples, and ultimately to the land the reserve was trying to protect. These reserves require both ecological and conceptual redress.

Many reserves have already suffered significant impacts from anthropogenic climate change, a history of fire exclusion, and changing conditions in neighboring lands. There is every reason to believe that these impacts will not only continue, but will accelerate. Thus, many old forest and wilderness reserves are not protected from ongoing insect outbreaks, wildfires, and a variety of the extreme effects of climate change. Continuing to conceive of and treat them as we have in the past, therefore, risks their very existence and the values we derive from them. This raises an important challenge for reserves: can our strategies for reserves be adapted over time to anticipate the direct and indirect threats to them such that we can maintain their value and actively adapt them to the changes that threaten them, and thereby secure their value for the future?

As policy makers consider the future of contemporary old and mature forests, in particular, questions remain about how to protect them from development and extractive uses while also allowing for proactive stewardship to adapt them to climate change and future wildfires. Considering the future impacts on these reserves articulated above, and in this report more generally, we believe designations that protect forests from development and harvesting are, at times, a necessary place-based strategy for their conservation. However, treating them as static and unchanging runs contrary to their dynamic nature and threatens their continued resilience and even existence.

The movement to create reserves to protect them from development and commercial exploitation happened at a time when many Euro-Americans believed these areas evolved without human influence. For some, this perceived lack of historical human influence is what makes reserves valuable. Such beliefs are, we now know, historically inaccurate. Indigenous Peoples occupied, were in active relationship with, and shaped these places (which were, and continue to be, their ancestral homelands) for millennia. This accounting also fails to acknowledge that Indigenous Peoples were often forcibly removed from their homelands to create these reserves.[12] Continuing to tie the value of reserves to their perceived lack of human influence, and to ignore the dispossession of Indigenous Peoples in their making, perpetuates an historical myth that is deeply offensive to, and traumatizing for, Indigenous Peoples, both past and present.

Arguably, the best illustration of this conceptual challenge is with wilderness. As it stands today, the concept of wilderness often suggests that wilderness is an area unaffected, or relatively unaffected, by humans and human activities. This concept of wilderness is currently codified in The Wilderness Act of 1964 [section 2(c)], which defines wilderness as: "*[an] area in contrast with those areas where man and his own works dominate the landscape . . . where the earth and its community of life are untrammeled by man, where man himself is a visitor who does not remain.*"[13]

In the early 1990s, historians, philosophers, and other Western and non-Western academics began to offer critiques of certain popular conceptualizations of wilderness (Callicott & Nelson 1998; Nelson & Callicott 2008). In doing this work, they uncovered even older critiques from Indigenous voices, such as Chief Luther Standing Bear (1868-1939) who wrote:

> *[F]or us there was no wilderness, nature was not dangerous but hospitable, not forbidding but friendly... We did not think of the great open plains, the beautiful rolling hills, and winding streams with tangled growth, as "wild." Only to the white man was nature a "wilderness" and only to him was the land "infested" with "wild" animals and "savage" people. To us it was tame.*[14]

It is important to note that while scholars have offered these critiques of wilderness, they also suggest these critiques are of the concept of wilderness, not necessarily of designated wilderness areas themselves. Likewise, a critique of the concept of mature and old-growth forest reserves does not necessarily devalue those forests we think of as mature and old-growth, as Indigenous scholar Victoria Yazzie expressed above.

We suggest that in the context of the best available IK and WS, old forests and wilderness areas can remain protected, even if in reserves. However, the thinking about and policies governing human interactions with these areas require revision. Those intellectual and policy revisions would include, as examples:

- The intentional re-introduction of practices such as cultural and prescribed burning, thinning, and other cultural practices within reserves to create climate resilience; requiring that we embrace both the idea that these places were historically peopled and that human intervention can, in principle and practice, be of benefit to the land. We believe that braiding IK and WS together can conserve existing old forests and help them adapt to fire and climate change. This assumption obviates the premise that good can (and did) come from the work of human hands, an idea successfully manifest across NA

12 Philip Burnham *Indian Country, God's Country: Native Americans and the National Parks, Robert Keller American Indians and the National Parks*, and Mark David Spence *Dispossessing the Wilderness: Indian Removal and the Making of the National Parks.*

13 The Wilderness Act of 1964 (Public Law 88-577), https://www.nps.gov/subjects/wilderness/upload/W-Act_508.pdf

14 Standing Bear, Chief Luther 1988. Indian Wisdom.

for millennia of human Indigenous presence and practice.

- A rethinking of the purpose of reserves. As an example, given the wisdom necessary to live in this world, wisdom that resides in the world itself, it would be unwise to knowingly disregard those forests where our oldest and wisest ancestors reside. The purpose of an old forest, therefore, is to provide places where we humans can – in the spirit of humility and reciprocity – learn from the elder trees, the old forest, and the world itself. Such a purpose provides a sound justification for protecting these places.

As such, we are not suggesting that reserves (e.g., parks, wilderness areas, or old-growth forests) be abandoned. We do, however, suggest that such concepts and labels be reconceptualized in light of their historic meanings and implications for Indigenous Peoples.

Finally, and perhaps most importantly, we believe in the power and imaginative capabilities of the human mind. We also believe in the necessity of the human mind to exercise that power and those capabilities in the face of our coming challenges. Our thinking about reserves such as parks, wilderness areas, and old-growth forests must evolve if we are to truly protect those places and find a way forward, together, in an uncertain future.[15]

Illustration by Miriam Morrill

WHY ECOCULTURAL CONDITIONS MATTER FOR CLIMATE CHANGE ADAPTATION

IN A NUTSHELL: We describe various ecocultural adaptations, with examples from US forest landscapes. We detail why these ecosystems represent an ecology of place and people. We then provide examples of how people, places, conditions, and practices can produce healthy outcomes for ecosystems and people.

Throughout this report, we describe forests as part of larger ecological and ecocultural systems. Wherever people live, they are part of the ecology of that place. In forested landscapes of NA, ecocultural systems emerge as people interact with place and actively shape the structure and composition of vegetation and its resilience to drought, fire, and other change-agents. For example, underburning pine, oak, and prairie systems reduces tree densities and favors large, older trees better able to survive drought and subsequent fires than younger, smaller trees. Intentional burning also maintains light understory fuels, which promote low-severity fires. Following Euro-American colonization, exclusion of Indigenous fire stewardship and fire suppression drastically reduced such practices.

For example, one of the most notable characteristics of fire-adapted oak and pine communities is their understories, which contain their flammable litter and grasses. Prior to colonization, Indigenous Peoples regularly burned oak and pine-dominated forests to keep them open. Long-needled pine litter is highly flammable and sufficiently continuous to facilitate frequent burning. Similarly, fire-adapted oaks have highly flammable litter layers when conditions are dry. Dead oak leaves tend to curl and dry relatively quickly compared to other broadleaf deciduous tree species such as aspen or maple (Kreye et al. 2013; Varner et al. 2022). Grasses and herbs pose a barrier to fire spread when green, but support fast-moving, low-intensity fires when dry in late summer and fall. Grass and herb fuels recover their moisture at nightfall, when relative

15 We acknowledge that our writing team embodies a spectrum of perspectives on wilderness and reserves. We all share an appreciation for our forests and concern about their future. Many of us recognize the critical importance of protecting forests from overharvesting, roads, and development, but we also acknowledge that concepts such as “pristine,” “untouched,” or “unpeopled” old forests, wildlands, or wilderness have their origins in settler colonialism. We acknowledge that Indigenous Peoples were often forcibly removed from their homelands to create reserves. From our work together, we conclude that respectful engagement with IK requires careful consideration of the language we use, the policies and rules that we apply, and the legacies of settler colonialism.

humidity increases. These fuels can slow the spread of fire until they re-dry and represent important daily to seasonal controls on fire behavior in frequent fire systems.

While understory plant species differ across frequent-fire forests and woodlands, their open, light-filled understories support diverse communities of herbs, grasses, and shrubs, highly valued by WS for their biodiversity and by IK for their cultural significance. Plants with Indigenous material uses include wood and fibers for shelter, tools, and clothing; foods and medicines including fruits and roots; and specialty products used for carving, weaving, and braiding ceremonial objects and regalia. The quantity, quality, and accessibility of these materials often depends on distinctive growing conditions, as well as continuing tending practices (Long et al. 2021). For example, repeated fine-scale cultural burning in beargrass habitat creates preferred chemistry, caliper, and flexibility of beargrass strands used for basket weaving (Hart-Fredeluces 2022).

Cultural burning practices were previously assumed by many Western scholars to be confined to areas near Indigenous communities; however, Indigenous knowledge systems and evidence from forests provide evidence that ecocultural systems were widespread across NA prior to Euro-American settlement (Long et al. 2021; Roos et al. 2022; Swetnam et al. 2016; Taylor et al. 2016). Historically, fire-adapted pine and oak systems dominated eastern temperate forests and forests across California, the desert Southwest, and Mexico. Today, these forest types are markedly reduced, in many places replaced by closed-canopy forests or cleared for land development (Hanberry et al. 2020; Haugo et al. 2019; Marschall et al. 2022; Suaeta et al. 2022). Some of the most threatened and endangered NA plants and habitats require frequent or moderately frequent fire (Bowman et al. 2016; Stephens et al. 2019).

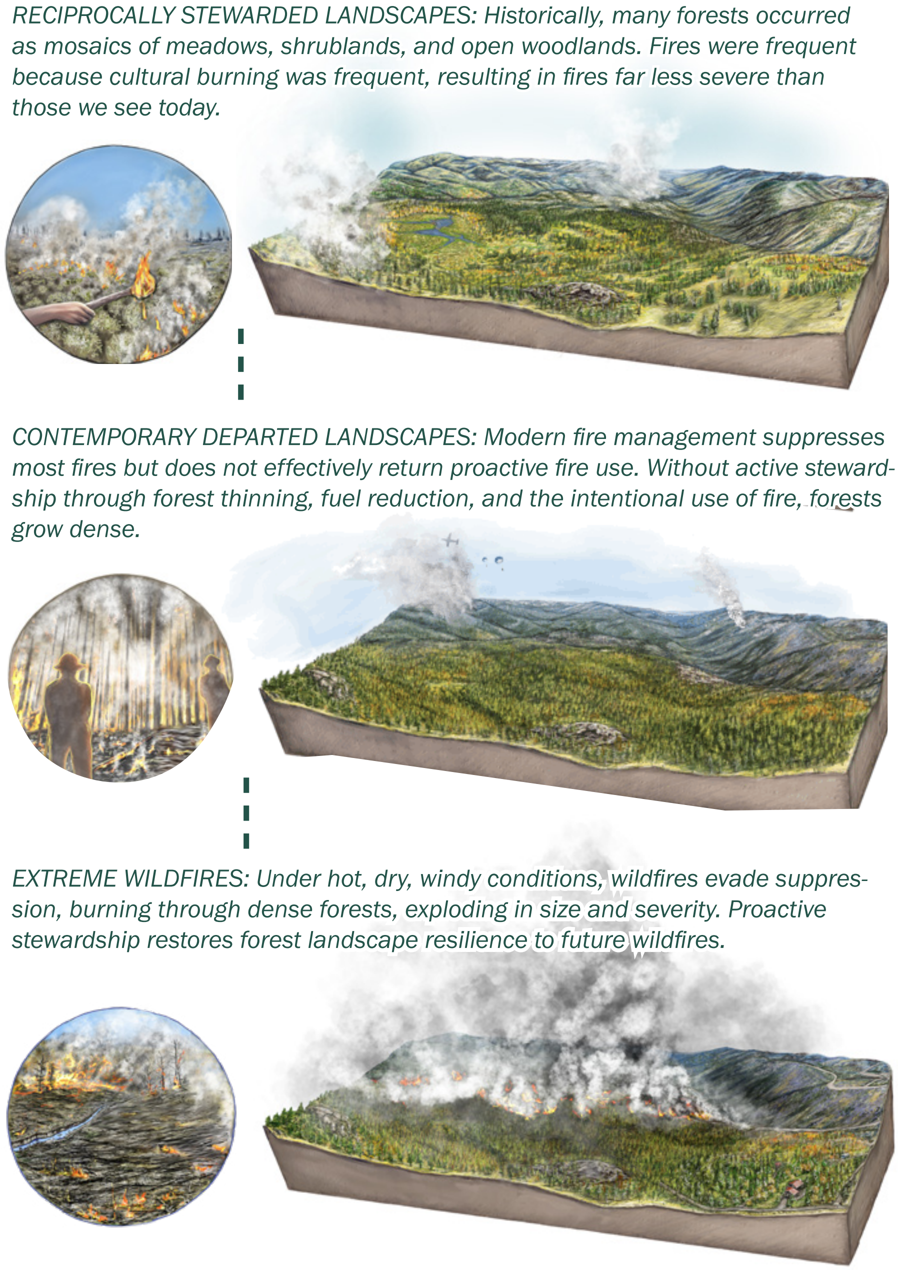

Figure 6. One of the most significant agents of ecological change, wildfires are projected to increase in area burned three-fold by 2050 under climate change. US active fire suppression extinguishes 97-98% of ignitions. However, the 2-3% of fires that escape suppression typically burn during extreme fire weather, accounting for over 90% of the annual area burned. This is the inverse of what historically occurred under cultural and lightning-ignited fire influences. Illustrations by Miriam Morrill.

Many closed-canopy forests that have replaced fire-maintained ecosystems are now maladapted to climate change and highly susceptible to drought, severe wildfires, forest insects, and pathogens (Coop et al. 2022; Hessburg et al. 2019; Varner et al. 2005; Varner 2018).

WS is a powerful tool for learning and is critical to our continued study of forest ecosystems and climate adaptation, but alone insufficient to address degraded forest communities that lack climate and wildfire resilience. Humility can bridge this knowledge gap. Restoring these forests requires honoring and understanding IK and weaving it with WS in Two-Eyed Seeing. To do so requires acknowledging and supporting Indigenous communities to reconcile their removal from landscapes they shaped and maintained for millennia, and then braiding together cultural practices informed by both worldviews. Ecocultural restoration focuses on proactive, adaptive stewardship that honors Indigenous Peoples' contributions and traditional wisdom. In WS parlance, adaptive stewardship is learning by doing. In IK parlance, Indigenous stewardship is the original adaptive management—how people learn from their work through keen, respectful observation over time.

POLICY BACKGROUND

IN A NUTSHELL: In this section, we provide policy background as core context to five recommendations with which we conclude Part 1.

By the 19th century, colonists had logged most primary forests in the eastern half of the present-day US to clear land for agriculture and development and supply timber to build a new nation. Once logged, land developers and timber companies quickly shifted their appetites to Western forests. To encourage and support westward migration and homesteading, in 1812 the US federal government created the General Land Office (GLO).[16]

The ecological devastation in the East was so extreme that by the late 1800s national leaders decided that something was needed to protect what remained of the young nation's forests and wildlife and to ensure sustainable timber and water supplies. Most of what remained resided in 11 western states. In response, Congress gave the President the ability to create Forest Reserves with the General Revision Act of 1891. President Harrison used the law to create 15 reserves comprised of 13 million acres, and President Cleveland used the law to reserve 25 million acres. The Organic Act of 1897 consolidated the individual Forest Reserves into a formal forest reserve system. It wasn't until the Transfer Act of 1905 that the forest reserves were transferred from the Department of Interior to the Department of Agriculture. The Transfer Act also created the US Forest Service and renamed the reserves "national forests." In 1905, Roosevelt appointed Gifford Pinchot as the first Chief of the Forest Service. In 1907, Congress acted to end the reservation of lands into national forests (Leshy 2022). In 1916, President Wilson created the National Park Service, to "*conserve the scenery and the natural and historic objects and the wildlife therein and . . . leave them unimpaired for the enjoyment of future generations*."[17] In 1946, President Truman merged the GLO and the US Grazing Service to create the Bureau of Land Management (BLM).[18]

Most of our modern environmental laws were inspired by 20th century conservation leaders Aldo Leopold, John Muir, Olaus Murie, and Rachel Carson, and the Public Lands Law Review Commission. The Commission's 1970 report recommended to Congress that it enact dozens of environmental laws that would eventually be known as the Clean Water and Air Acts, the ESA, and others.[19] The need to conserve and protect US forests and clean air, water, and wildlife resources catalyzed the environmental movement of the 1960s and 1970s. That movement was founded on a lived distrust of 19th and 20th century forestry, forest management, and most harvest methods. By the 1990s, the movement oversaw a 90% reduction of timber harvested on public lands. Additionally, much like federal policy approaches of this time, the environmental movement and federal government downplayed the presence, historical impacts, and Sovereignty Rights of Tribal Nations.

In 1976, the Intertribal Timber Council (ITC) was established to improve management of natural resources important to Native communities. This nation-wide nonprofit consortium of Indian Tribes, Alaska Native Corporations, and individuals is

16 History of the BLM, https://www.blm.gov/about/history

17 USDA Forest Service, Our History, https://www.fs.usda.gov/learn/our-history; Organic Act of 1916, https://www.nps.gov/grba/learn/management/organic-act-of-1916.htm

18 History of the BLM, https://www.blm.gov/about/history

19 US National Archives 2024, https://www.archives.gov/research/guide-fed-records/groups/409.html

dedicated to empowering Indigenous Peoples in forest stewardship and policy decisions. Primary among those empowerments is giving them a seat at key decision-making tables and strengthening Government-to-Government relationships.[20] Even so, Tribal Nations have often not been effectively engaged in developing federal forest policy (Long & Lake 2018).

NFMA and other laws and policies have beneficially guided National Forest management. However, they are limited in their ability to address contemporary

20 Intertribal Timber Council website: https://www.itcnet.org/

KEY 20TH CENTURY LAWS GOVERNING PUBLIC LAND MANAGEMENT

THE WILDERNESS ACT OF 1964 established the National Wilderness Preservation System, a national network of 762 federally-designated wilderness areas on 111 million acres of public land. The wildest of our wildland areas are managed under this Act by the National Park Service, BLM, US Fish and Wildlife Service, and FS to preserve their wildland character. The Wilderness Act prohibits timber harvest.

THE NATIONAL ENVIRONMENTAL POLICY ACT (NEPA) OF 1970 requires that all branches of the federal government sufficiently consider the affected environment before undertaking any action that may significantly affect those environments. NEPA applies to proposed management actions in forests and rangelands under federal management.

THE ENDANGERED SPECIES ACT OF 1973 (ESA) provides a means of preventing the extinction of native species by promoting conservation of individual listed species and their habitats. It requires the preparation of recovery plans, reducing identified threats to species persistence, and provides a mechanism to “delist” species that have recovered to the point that the Act’s protections are no longer necessary.

THE CLEAN AIR ACT OF 1975 regulates air emissions from stationary and mobile sources. The Clean Air Act (CAA) authorizes EPA to establish National Ambient Air Quality Standards (NAAQS) to protect public health and public welfare and regulate hazardous air pollutants emissions. The Act limits prescribed burning and Indigenous cultural burning due to the smoke that these practices create.

THE NATIONAL FOREST MANAGEMENT ACT OF 1976 (NFMA) is an amendment of the Forest and Rangeland Renewable Resources Planning Act of 1974 (RPA). NFMA establishes standards for how the FS manages national forests and grasslands, requires the development and timely revision of land management plans for each national forest and grassland, and directs the FS to regularly report the status and trends of our Nation’s renewable resources on all public lands. NFMA was enacted following fierce public debates over the wisdom of widespread clear-cutting. To protect national forests from excessive and destructive logging, Congress instructed the FS to regulate the size of clearcuts, protect streams from logging, regulate the annual allowable harvest, and ensure prompt reforestation.

THE FEDERAL LAND AND POLICY MANAGEMENT ACT OF 1976 (FLPMA) is the Bureau of Land Management’s “organic act” that establishes the agency’s multiple-use and sustained yield mandate to serve present and future generations.

THE CLEAN WATER ACT OF 1977 (CWA) was a major revision of the 1948 Federal Water Pollution Control Act. It established a framework for regulating pollution in US surface waters and protects the right of Americans to clean, safe, and biologically intact waterways. It ostensibly regulates the discharge of untreated wastewater from businesses, industries, and municipalities into river, lakes, and coastal waters. The CWA strengthened authorities of the US Environmental Protection Agency (EPA), and requires industry to meet best available pollution control technology standards for specified toxic pollutants.

and future issues for forests.[21] There have been improvements since NFMA, such as the 2012 Planning Rule, that better account for contemporary and future threats. Nevertheless, long-term forest planning processes inherently struggle to stay contemporary. Current threats include rapidly changing climate and wildfire regimes, and encroachment of invasive species of plants and animals. Forests are highly departed from historical conditions and poorly adapted to future conditions, and wildfires have greatly increased in size, frequency, and severity. Lack of resources needed to address fire at the pace and scale exacerbates these problems. A reduced firefighting work force is expected to work through longer and more severe fire seasons (Thompson et al. 2023).

It is starkly apparent that our Nation's forests are in crisis. It has become clear to the US federal government that WS alone cannot fully provide the insights and proactive strategies to effectively increase their climate adaptation. The federal government, and particularly this White House, recognize Tribal engagement and IK as an essential path forward.

Accordingly, in November 2021, Secretary of Interior Deb Haaland and Secretary of Agriculture Tom Vilsack signed Joint Secretarial Order 3403.[22] Its purpose is to ensure federal lands and waters are managed in a manner that protects the treaty, religious, subsistence, and cultural interests of all 574 federally recognized Tribal Nations. This federal trust responsibility is a legal obligation, originally articulated in treaties, to protect Tribal lands, assets, and resources. JSO 3403 calls for the Department of Agriculture and Department of interior to "Make agreements with Indian Tribes to collaborate in the co-stewardship of Federal lands and waters under the Departments' jurisdiction, including for wildlife and its habitat." Effective engagement can take a variety of co-stewardship formats including sharing technical expertise, combining Tribal and federal agency knowledge and capabilities to improve resource-management practices advancing the responsibilities and interests of each, and making Tribal knowledge and perspectives integral to the public's experience of federal lands. Co-management can result from co-stewardship, and as the result of more extensive deliberation and negotiation to jointly make decisions.[22]

To support these values and federal policies on working with IK and partnering with Indigenous Peoples, the OTR published the *Strengthening Tribal Consultation and Nation-to-Nation Relationships USDA Forest Service Action Plan 2023*. In the words of Randy Moore, Chief of the USDA Forest Service, "We can start doing this by creating space for Indigenous Nations to share the knowledge and expertise they possess through their longstanding relationship with the land." In doing so, he emphasized the federal government's full commitment to strengthening Government-to-Government relationships with a focus on co-stewardship. OTR Director Reed Robinson sees co-stewardship as about merging "shared governmental ideals and USDA Forest Service values with the Indigenous understanding of *Mitakuye Oyasin* (interconnectedness)."[23]

Federal executive orders and memoranda pertaining to IK and Tribal Sovereignty give standing and validity to IK equal to WS.[23] In November 2022, the White House OSTP and CEQ published the memorandum, *Guidance for Federal Departments and Agencies on Indigenous Knowledge*. It harkens a new era of Indigenous Self-Determination and Tribal Sovereignty in the US.[24] This is the first time the Office of the President and the White House have issued such decolonized formal statements.[24]

White House OSTP and CEQ guidance aims to help federal agencies understand IK, develop and maintain mutually beneficial relationships with Tribal Nations, and incorporate IK in federal policies and practices. It states that "In light of the injustice and marginalization of Indigenous Peoples, it is incumbent on agencies to make sustained efforts to build and

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21 Mature and Old-Growth Forests: Definition, Identification, and Initial Inventory on Lands Managed by the FS and BLM https://www.fs.usda.gov/sites/default/files/mature-and-old-growth-forests-tech.pdf ; https://www.fs.usda.gov/managing-land/old-growth-forests

22 J SO 3403, Fulfilling the Trust Responsibility to Indian Tribes in the Stewardship of Federal Lands and Waters. https://www.doi.gov/sites/doi.gov/files/elips/documents/so-3403-joint-secretarial-order-on-fulfilling-the-trust-responsibility-to-indian-tribes-in-the-stewardship-of-federal-lands-and-waters.pdf

23 Strengthening Tribal Consultation and Nation-to-Nation Relationships USDA Forest Service Action Plan 2023 https://www.fs.usda.gov/sites/default/files/fs_media/fs_document/Strengthening-Tribal-Relations.pdf

24 OSTP CEQ 2022 Guidance for federal departments and agencies on Indigenous Knowledge. https://www.whitehouse.gov/wp-content/uploads/2022/12/OSTP-CEQ-IK-Guidance.pdf

maintain trust to support Indigenous Knowledge,"[24] and that,

> *Agencies should include the following principles and practices:*
> *1) Acknowledge historical context and past injustice*
> *2) Practice early and sustained engagement*
> *3) Earn and maintain trust*
> *4) Respect different processes and worldviews*
> *5) Recognize challenges*
> *6) Consider co-management and co-stewardship structures*
> *7) Pursue co-production of knowledge*[24]

Other institutions have created complementary guidelines. In 2020, the Native Nations Institute at the University of Arizona created the *CARE Principles for Indigenous Data Governance*; CARE stands for "Collective benefit, Authority to control, Responsibility, and Ethics"(Carroll et al. 2020). These globally applicable principles call for data ecosystems to be designed and function in a manner that allows Indigenous Peoples to benefit from data. The US federal government actively uses them to inform emerging federal policies on Indigenous data governance (Jennings et al. 2023).

The Indigenous Natural Resource Office at the Oregon State University (OSU) College of Forestry (CoF), a North American and global leader in forestry and forest science, has created the *Principles and Best Practices for Working with Indigenous Knowledge and Partnering with Tribal Nations and Indigenous Peoples*. This policy document applies to the OSU CoF specifically, for any projects that involve working with IK and Indigenous Peoples. Like any top research academic institution, a high proportion of the science done at OSU is federally funded. As such, these principles align with the federal guidelines listed above and are closely tailored to an academic environment.[25]

* * *

How then do we implement and scale our recommendations at a time when, given the magnitude of the challenges we are facing, time is of the essence? Working with Tribal Nations requires patience and trust-building, because of deep collective trauma done to Indigenous Peoples. Yet, we are at a moment in time when forest degradation and urgency to adapt to rapidly changing ecological conditions can bring us together across cultures. Rebuilding and maintaining that trust will be key.

The recommendations that follow provide specific guidance for improving forest climate adaptation. Part II of our report then offers in-depth regional strategies. Now is the time to implement the Seventh Generation Principle to restore climate resilience to our nation's forests and adopt an ethic of reciprocal stewardship.

FIVE RECOMMENDATIONS: FOUNDATIONS OF ECOCULTURAL RESTORATION

To meet today's challenges, strategies that weave together IK and WS can both inspire and catalyze work in NA forests at the pace and scale needed. We offer the following recommendations to restore resilience to our nation's forests:

1. ADOPT PROACTIVE STEWARDSHIP.

In historically frequent-fire forests, invest broadly and intentionally in active cultural and prescribed burning, forest thinning, and other active forest management at the pace and scale needed to overtake the influence of modern wildfires, restore resilience, and reduce reliance on fire suppression and disaster response. Maintaining climate resilience for large suites of ecosystem values will require a diversity of prescriptions and trials based on geographic and site-specific contexts of climate, vegetation, disturbance, terrain, and human communities. Dry, moist, and cold forests will be available to burn in most wildfire seasons. Thus, it will be important to recognize that patches of late-successional and old forest in most geographies and forest types will shift dynamically through space and time because of changing fire weather, disturbance regimes, and their irrepressible dynamism. Additional threats posed by drought, insects and pathogens, and an expanding wildland urban interface (WUI) also call for dynamic stewardship. An adaptive, proactive, stewardship model, guided by IK and WS co-stewardship methods, is needed to restore cultural practices and conserve forest landscapes (Table 1).

25 OSU College of forestry, Principles and Best Practices for Working with Indigenous Knowledge and Partnering with Tribal Nations and Indigenous Peoples. https://www.forestry.oregonstate.edu/sites/default/files/Principles%20and%20Best%20Practices%20Volume1%20Final.pdf

2. RECOGNIZE AND RESPECT TRIBAL SOVEREIGNTY AND INDIGENOUS KNOWLEDGE.

Establish and support Government-to-Government co-stewardship partnerships with Tribal Nations at all stages of policy development, planning, monitoring, decision-making, and adaptive stewardship. Portfolios of Indigenous and Western practices can then follow this process, reflecting shared stewardship and management of federal lands and ancestral homelands.

3. PROVIDE THE FLEXIBILITY TO STEWARD DYNAMIC LANDSCAPES AND NAVIGATE UNCERTAINTIES UNDER RAPIDLY CHANGING CONDITIONS.

Managing for static landscape conditions has been ineffective with respect to changing climatic and disturbance regimes. Especially under climate change, high-severity fire, drought, and insect disturbances cannot be prevented in areas prioritized for mature and old-growth forest conservation without adaptation. All landscapes, even designated reserves, are dynamic. Old forests have been and will continue to be an emergent property of large-scale wildfire and climate dynamics. Strategies that focus on maximizing the extent and continuity of what are often maladapted mature and old forests after fire exclusion are prone to the greatest failure due to the influences of climatic changes and related changing wildfire regimes. Thus, it is critical that fire be re-introduced and that adaptation to active fire regimes be restored. Proactive cultural stewardship practices that promote a diverse mix of ecological conditions, including but not limited to old forests, can assist in maintaining resilient mosaics of forest and nonforest and varied age classes of open and closed canopy structure.

4. GROUND AGENCY PLANNING, AND LAND AND RESOURCE STEWARDSHIP POLICIES IN ETHICS OF RECIPROCITY AND RESPONSIBILITY TO MANY FUTURE HUMAN GENERATIONS.

Through active reciprocal stewardship, people benefit from and provide for the ecosystems that support them for generations. Although ethics of reciprocity and responsible stewardship resonate for many, there is also a legacy of distrust in the capacity of agencies to engage in responsible stewardship. As we grapple with climate change, wildfires, human community needs, and rapidly changing forest conditions, a key challenge for public land managers is to cultivate an ethic of stewardship that is both proactive and centered on ethics of reciprocity and responsibility to future generations. Community benefits including sustainable harvest levels are in alignment with ecologically and culturally suitable place-based approaches to land stewardship. Such ethics are essential for reframing stewardship of public lands, including the ancestral homelands of Indigenous Peoples.

5. CATALYZE INNOVATIVE APPROACHES TO FOREST STEWARDSHIP.

IK is a key source of best-available scientific information. Indigenous stewardship practice that is part of IK is the original adaptive management and an historically proven and powerful cornerstone of resilient ecocultural systems. When braiding sweetgrass, adaptive stewardship involves the use of best available IK and WS and a continued investment in learning while doing. These learnings inform continual modification of best practices. Hence, effectively funding adaptive, long-term, forest stewardship, and long-term monitoring of that stewardship at stand-to-landscape scales is essential to all partnerships and many actions. IK and WS research investments are needed to support that monitoring of restorative management trials. Such research reveals the changing resilience needs of forest landscapes. Varied management trials that have the best IK and WS support can be implemented to grow both knowledge and practice. Practitioners then have freedom to try and learn from a range of successes and failures within a rapidly changing climate and environment.

Illustration by Miriam Morrill

Table 1. Examples of proactive stewardship strategies. Part II of this report contains additional descriptions and place-based examples. More place-based examples can be viewed online at adaptiveforeststewardship.org/map.

Strategy	Description	Examples
Restore climate and fire resilient and culturally significant species composition and structure	Following fire exclusion, many sites require mechanical treatments such as thinning, selective harvest, and the restoration of openings to favor climate and fire-resilient and culturally significant species. Mechanical treatments can then be followed by regular cultural and prescribed underburning.	Pine-oak woodlands in the SW US, California, eastern and southern US, ponderosa and Jeffrey pine forests of the western US; dry and moist mixed conifer forests of the eastern Cascades, Sierra Nevada, SW US, northern and southern Rocky Mountains
Steward for old trees and old forests	Designate land where ecocultural stewardship and conservation will be used to promote old trees and old forests. Designations account for landscape dynamics, and disturbance drivers including fire, insect, disease, and wind; allow for adaptive management and dynamism; and support reciprocal relationships between forests and local communities.	NWFP Northern and California spotted owl forests, marbled murrelet forests as open woodlands with wolf trees (large trees with wide-spreading crowns); interior Cascade, Rocky Mountains, and Sierra Mountains dry and moist mixed conifer forests; Coast Range forests and their widespread meadows; SW US pine and mixed conifer forests.
Restore prairies, meadows, shrublands, and chaparral, woodlands, mid- and upper- elevation berry fields	Ecocultural restoration often involves underburning forests and opening prairies, grasslands, and berry fields. This can be accomplished through mechanical forest clearing and burning or intentional fire use over time in areas important for culturally significant food production.	Redwood National Park; Konza Prairie; Willamette and Rogue River Valleys; Red pine, Longleaf and shortleaf, pitch pine; and eastern redcedar
Support of material culture	Indigenous practitioners support cultural needs for materials such as basketry, regalia, foods, medicines, and timber through carefully timed stewardship practices, including cultural burning.	All Indigenous Peoples and their communities' cultural practices
Invest in adaptive stewardship and monitoring	Stewardship is a process of learning by doing. Rapid climate change will especially require careful monitoring using both IK and WS and capacity to course-correct from experiments that fail. Failures and unexpected outcomes are instruments of teaching and learning.	Expanded investments in seed orchards and monitoring; postfire restoration treatments; and adaptive planting, including lower stocking on dry sites. Adaptive stewardship invests in learning while doing.
Work with wildfires	Look for opportunities to expand the beneficial role of lightning ignitions. Proactive fuel reduction and burning can be used to allow for unplanned ignitions in remote locations.	Wildfire will outpace proactive treatments for the foreseeable future. Use wildfires as opportunities to re-introduce beneficial fire. Half of current burned acres are an acceptable first fire re-entry.
Proactive strategies for post-disturbance landscapes	Wildfires, hurricanes and other agents of change are increasing in both severity and frequency. Planning for these events and post-disturbance response across large areas is needed.	Post-disturbance landscapes pose both challenges and opportunities. Fuel accumulations following wind and fire events often require reduction to mitigate future fire and insect damage.
Guide change through cultivation and stewardship	In strict keeping with Tribal Data Sovereignty and working in protected partnerships with Tribal Nations (e.g., with memoranda of understanding and other agreements), learn where culturally significant plants and animals may occur as the climate changes.	Cultural stewardship in Vancouver Island and BC coastal forests and Oregon Coastal forests; prairie burning to increase prairie and woodland conditions.

EXAMPLES OF PROACTIVE FOREST STEWARDSHIP IN ACTION

Fire burns through a past treatment during the 2015 Sawmill Fire in Arizona. Photo Credit: Inciweb.

RESTORATION OF MIXED-CONIFER FORESTS BY THE HUALAPAI NATION AND SAN CARLOS APACHE TRIBE

Across the interior West, many frequent-fire ponderosa pine and mixed conifer forests are profoundly departed from their historical structure and composition. Fire suppression policies and curtailment of Indigenous cultural burning have created dense, fuel-loaded forests vulnerable to abnormally severe fire and prolonged drought. These dense forests now shade out understory plant communities important to Indigenous Peoples, while high-severity fires threaten wildlife habitat, timber, and other forest resources, and cultural values.

The Hualapai Nation in western Arizona and the San Carlos Apache Tribe in southeast Arizona are restoring the ecocultural integrity of mixed-conifer forests in their ancestral homelands using uneven-aged silvicultural treatments, prescribed burning, and managed wildfires. Fire history and IK guide treatments and fire-return intervals. These proactive forestry and fire management programs have increased ecosystem resilience, while promoting important cultural values, such as improved habitat for large game species, sustainable timber supplies for local economies, and understory biodiversity.

Prescribed burning in an eastern white pine stand. Photo Credit: Forest Management Plan, Page 99.

ECOCULTURAL RESTORATION IN PINE-HARDWOOD FORESTS OF THE MENOMINEE TRIBE

The diverse forest types of northern Wisconsin, the ancestral territory of the Menominee People, have experienced widespread change since Euro-American colonization. Historically, Indigenous cultural burning and other stewardship practices maintained mosaics of oak woodland, red and white pine, mixed pine and oak forests, with interspersed northern and transitional hardwood stands. Widespread clear-cut logging in the 1800s and early 1900s, extremely large, high-intensity fires burning through slash after high-grade logging, and 100+ subsequent years of fire suppression on federal forests, also impacted Tribal forests. Without fire, these landscapes lost pine and oak woodlands and instead supported transitional hardwood stands of aspen and birch, northern hardwood stands of basswood, beech, ash, and maple, with eastern hemlock and balsam fir.

Menominee restoration practices offer an inspiring example of ecocultural restoration. The Tribe employs a variety of silvicultural approaches, including even- and uneven-aged prescriptions, prescribed burning, and passive management to mimic Indigenous-influenced disturbance regimes, and moderate fire severity. All management is founded on practices of reciprocity and multi-resource management. Managers strive to provide sustainable timber products to the Menominee people, while maintaining wildlife habitat, enhancing aesthetics, protecting cultural resources and archaeological sites, and improving soil and water resources. The diversity of Tribally managed cover-types and use of demonstration sites to test alternative treatments ensure forest climate-change adaptation.[26]

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26 Forest Management Plan (Revised 1973) 2012-2027. Menominee Tribal Enterprises. Available at: https://www.mtewood.com/Content/files/ForestManagementPlan.pdf. Menominee Tribal Enterprises. https://www.mtewood.com/

PART II: REGIONAL STRATEGIES

Illustration by Jessie Thoreson

BOREAL AND HEMIBOREAL FORESTS

Lead Authors: M. Parisien, H. Asselin, A. Christianson, E. Grant, R. Gray, G. Proulx, and E. Whitman

GEOGRAPHY AND CLIMATE

The boreal biome is an important cultural landscape for hundreds of Indigenous Nations. The largest biome in North America, it represents an area of over 6.5 million km^2 – extending from the Atlantic to the Pacific and Arctic Oceans. Considered here also is a transitional hemiboreal zone, lying between boreal and temperate zones, which shares many of the same biological and physical features, but includes hardwood and coniferous species found in temperate forests further south (Figure 1).

The geology and relief of the region varies substantially, from the rocky bedrock of the Canadian Shield in the eastern and central portions of the biome, to the deep marine sedimentary region of western Canada and interior Alaska, and the Pacific Coastal and Rocky Mountain Cordilleras in the West. The Shield is a large geologic area of exposed Precambrian igneous and metamorphic rock forming the ancient geologic core of the North American continent. This region holds globally significant freshwater reserves and is covered by countless lakes, rivers, and wetland complexes, many of which are peat-forming. Peatlands, which are ubiquitous in the biome, form thick (often > 5 m) organic soils that contain immense carbon reserves.

Although this vast boreal and hemiboreal zone is characterized by long, cold winters and short, warm summers, it is subject to strong climatic gradients. For example, there is a north-to-south latitudinal gradient of increasing temperature, a coastal-interior precipitation gradient of decreasing moisture, and complex elevation and aspect-driven local to subregional climatic gradients that affect local temperature and precipitation patterns. Conifer dominance in forests generally increases northward into the boreal, but broadleaf species are locally abundant in more southerly boreal and hemiboreal areas under suitable topoedaphic and disturbance conditions. Tree canopy cover is also highly variable, with open forests being more common in northern boreal and peatland complexes. To the south, the hemiboreal zone transitions to broadleaf and mixedwood (mixed conifer and hardwood) forests in the eastern and Great Lakes area, to grassland ecosystems in the Canadian Prairies and Great Plains, and to a variety of temperate conifer, hardwood, and mixedwood forests west of the Continental Divide and in Alaska in the far western part of the biome.

CLIMATE AND WILDFIRE ADAPTATION STRATEGIES

As in other North American forests, mature and old boreal forests face threats from climate change and increasing wildfire activity. However, there are unique challenges in this region requiring specific approaches for mitigation. Most of the current boreal-hemiboreal region's wildfire regimes are characterized by large, high-intensity fires that are generally lethal to trees or to the dominant lifeform, if other than forested. This has not always been the case. As with most North American fire regimes, most historical fires were small- to medium- sized, but most area was burned by the largest fires. Further, much of the landscape was in some stage of being recently burned or recovering. This patchwork of burned and recovering conditions influenced the frequency of the largest fires. After a long period of fire suppression and fire exclusion, patchworks give way to continuous forests that are highly susceptible to large and severe fire events.

Through a strong co-evolution with wildfire since the retreat of the continental glaciers, biological communities of the boreal-hemiboreal region are hardwired to endure and regenerate following wildfires. Such regeneration best occurs when the frequency-size distribution of fires yields many smaller patches and fewer very large patches. In this context, boreal landscapes represent a dynamic mosaic of patches of different ages, sizes, size classes, canopy cover conditions, and species mixes that collectively support a diverse biota.

There are, however, limits to forest resilience with respect to disturbance rates. Too much fire and short reburning cycles threaten forest recovery and compromise ecological resilience (Stevens-Rumann et al. 2022). At the same time, a recent decrease in fire occurrence in some areas of the region, due in part to human land use and management practices, has disrupted fire-climate-vegetation dynamics (Chavardès et al. 2022; "Environment and Climate Change Canada" 2023; Kelly et al. 2013; Stevens-Rumann et al. 2022). Regardless of the disturbance legacy, the record-breaking wildfire seasons of 2017, 2018, and

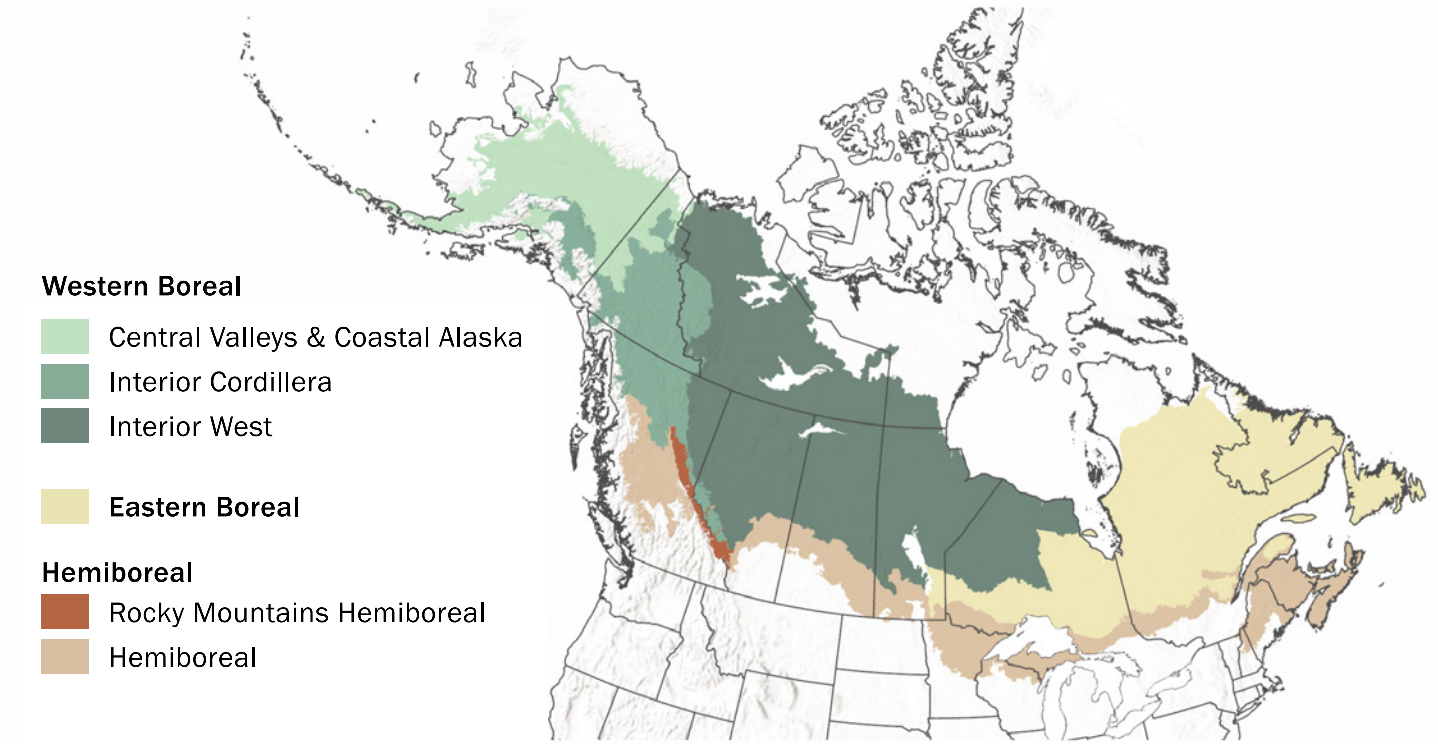

Figure 1. The boreal and hemiboreal region of North America.

2023 in Canada have shown that the rapidly changing climates in the North (e.g., 1.9 ºC of warming already experienced in Canada, on average; Environment and Climate Change Canada 2023) are translating into substantial and widespread increase in wildfire potential.

For strategies that sustain mature and old forests in this region to work, it is essential to consider the current inherent tendency toward severe fire and recognize that old forest stands have likely originated from wildfire and will eventually burn. Across much of the region, however, the past may not provide a solid frame of reference for the future, given the ongoing and accelerating rate of climate change. Species dependent on old forest habitats, such as woodland caribou, require special attention in terms of habitat protection. Due to the high spatial and interannual variability in weather patterns and wildfire activity characterizing the dynamic nature of the boreal landscape, flexible approaches such as variable conservation area boundaries and weather-driven restrictions in forest use may be appropriate. Where stand-replacing wildfires are undesirable, beneficial fires through cultural burning, prescribed fire, and mechanical treatments are options.

In areas severely affected by wildfire, repeated severe fire (i.e., short interval reburns), or intense post-fire drought, bold approaches such as species translocation or replanting, typically not practiced in post-burned boreal forests, may be advantageous where a developing divergence between local tree species and altered climate exists. A broader range of strategies for climate and wildfire adaptation in boreal forests are reported in Table 1.

IMPACTS OF SETTLER COLONIALISM

Indigenous fire stewardship shaped large swathes of the boreal biome up to the point of European contact. Thousands of years of Indigenous fire practice exerted significant ecological and evolutionary influences on ecosystem composition, structure, and processes. Indigenous Peoples were also reliant on lightning-caused fires to assist them in achieving biodiversity across vast landscapes (Miller & Davidson-Hunt 2010). In Indigenous traditions, fire is viewed as a tool used to produce desired outcomes on the land, and a natural agent of landscape change (Christianson et al. 2022). Historically, Indigenous Peoples used timber and other forest resources extensively. Individual-tree and small-patch harvesting practices were often developed in concert with their use of fire (Berkes & Davidson-Hunt 2006; Copes-Gerbitz et al. 2021). There were

Table 1. Adaptation toolbox for protecting and restoring boreal and hemiboreal forests. Table continued on the next page.

Adaptation strategy	Description	Ecocultural system(s)	Threat(s) addressed
Beneficial fire, surface fire	Frequent cultural and prescribed burning around valued assets and across large tracts (> 100 ha) of the landscape	Southern Canadian Rockies; other areas	Loss of old forests due to large, high-intensity wildfires Decline in keystone species Landscape-scale fires
Beneficial fire, mixed-severity fire	Cultural and prescribed burning, and managed wildfires designed to enhance or control natural forest regeneration, often conducted in the fall	Eastern boreal forests; other areas	Uncontrolled, high-intensity wildfire close to assets Loss of forest resilience (e.g., tree recruitment and growth) Insect outbreaks (continuous host forests)
Tree-species dominance shift	Strategically promoting certain tree species (e.g., less-flammable broad-leaf trees) through forest-management activities and beneficial fire	All	Loss of old forests due to large, high-intensity wildfires Increased wildfire risk to communities Loss of early seral habitats and habitats associated with hardwood forests
Dynamic protected areas	Creating an interconnected system of protected areas that vary as a function of natural and human disturbances; spread both the positive and negative of wildfires across the land	All	Substantial and sudden loss of a protected area's forest cover Loss of cultural and recreation value Lack of representative forest age classes
Monitoring of overwintering wildfires	Predicting and detecting overwintering wildfires in deep organic soils (e.g., peatlands) to strategically limit burning of areas of interest	Western boreal forest	Loss of critical woodland caribou habitat Increased wildfire risk to communities
Temporary and variable regulations of uses or activities triggered by extreme fire weather conditions	Automatically enacting regulations such as forest area closures, equipment use and burning restrictions, and speed limits for trains under extreme weather conditions identified from real-time local weather data	All	Loss of old forests due to large, high-intensity wildfires Increased wildfire risk to communities
Strategic fuel breaks	Strategically locate fuel treatments (e.g., thinning, prescribed burning, fuel breaks) to protect values (old growth, habitat, communities) where they are vulnerable to large fires and the occurrence of a severe wildfire is unacceptable	All	Loss of old forests due to large, high-intensity wildfires Loss of critical habitat Increased wildfire risk to communities
Reburning	After assessing fire flow patterns, maintain areas recently burned in early seral condition where there is a high probability of fire recurrence	All	Loss of old forests due to large, high-intensity wildfires Loss of critical habitat Increased wildfire risk to communities

Table 1. Adaptation toolbox for protecting and restoring boreal and hemiboreal forests. Continued from previous page.

Adaptation strategy	Description	Ecocultural system(s)	Threat(s) addressed
Riparian restoration	Riparian systems, especially rivers and creeks historically impeded fire flow; currently they do not and when burned exhibit high fire and burn severity	All	Loss of old forests due to large, high-intensity wildfires Loss of critical habitat Increased wildfire risk to communities
Reduction of the intensity of post-fire salvage logging	Maintain some of the burned trees and stands to provide wildlife habitats and to promote natural stand regeneration	Eastern	Loss of habitats of wildlife species dependent on recently burned trees or stands (e.g., three-toed woodpecker) Soil compaction by machinery during salvage logging negatively affecting site quality for natural regeneration.
Post-fire tree planting and tree species translocation	In severely burned areas that are unlikely to naturally regenerate as forest due to a lack of seed sources or severely altered climate, replanting of desirable (e.g., low-flammability trembling aspen) or climate-adapted (e.g., southern provenances) tree seedlings may be pursued	Dry forests and reburned areas	Loss of forest habitat and tree cover Decline in natural post-fire forest regeneration Increased wildfire risk to communities
Maximize the use of very large, severe wildfires.	In areas where large-scale fuel treatment, alternative fire strategies, or increased suppression are impractical or impossible, very large wildfires may provide benefit from a fire protection (i.e., by acting as a fuel treatment) and ecological restoration standpoint	Central valleys and coastal Alaska and the Yukon	Increased wildfire risk to communities Loss of old forests due to large, high-intensity wildfires in sensitive ecosystems Insect outbreaks (continuous host forests)

many reasons for burning in this region, including promoting berry and medicinal plant production, improving hunting, producing firewood and basketry materials, creating and maintaining trails, and driving game. However, relationships with fire varied among Indigenous Peoples, and some did not burn (Lewis & Ferguson 1988).

From the late 18th century through to the mid-21st century, colonial policies and practices greatly affected Indigenous influences on the landscape. Whereas historical fire stewardship was applied to establish mosaics across landscapes, its application was abolished after Euro-American colonization. Fire exclusion policies and the creation of the Canadian Indian Act caused the mass displacement of Indigenous Peoples to government-selected reserves and reservations away from traditional ancestral territories. Wildlife species, such as bison, vital to subsistence and culture of Indigenous Peoples were nearly extirpated. The population of Indigenous Peoples across the boreal was also greatly diminished due to introduced settler, trapper, and trader diseases, genocide, murder, and attrition.

While changes in governance came late relative to other parts of North America, they had a rapid and profound impact on peoples and ecosystems of the boreal and hemiboreal zones. In Alaska, the Alaska Native Claims Settlement Act (ANCSA) of 1971, in combination with the Alaska National Interest Lands Conservation Act (ANILCA) of 1980, replaced Indigenous stewardship with federal land management. Similar wholesale change in management systems occurred in vast expanses of boreal Canada through the so-called ‘numbered treaties’ of the late 19th and early

20th centuries (Langton 2004). Like many other areas of the continent, governance changes in the boreal and hemiboreal zones largely prohibited the use of fire, which many Indigenous Peoples saw as medicine for the land, and imposed modern fire-suppression policies. Colonists saw fire as a destructive agent, one to be suppressed to prevent destruction of settler communities and valued timber resources (Miller et al. 2010). These government policies and actions greatly affected who could burn, acceptable reasons for burning, and where burns could take place. In British Columbia (BC), for example, cultural fire was outlawed by the Bush Fire Act of 1874 and treated as a capital offense. The removal of fire from these ecosystems took two forms: the exclusion of active fire stewardship and the attempted complete suppression of all wildfires. As earlier frequent fire declined across boreal North America (Chavardès et al. 2022), modern day fire regimes became dominated by large, infrequent, and severe fires, with lightning ignitions responsible for most of the burned area (Danneyrolles et al. 2021; Hanes et al. 2019).

In contrast, Indigenous cultural fires contributed to many more numerous (100 to 1,000-fold) small fires that are now uncommon in Indigenous ancestral territories. This is due to the combined effects of forced separation of Indigenous Peoples from their cultural practices and readily effective fire suppression of the many small fires that burn under moderate fire weather conditions (Lewis & Ferguson 1988; Wallenius et al. 2011). Ironically, the ecological consequences of these drastic changes in fire management generally augmented the risk to people and communities by increasing flammable forest fuels and their connectivity across the landscape (Hessburg et al. 2019; Stockdale et al. 2019b). These twin changes also diminished the biological diversity of boreal landscapes (Burton et al. 2008) and contributed to forest-health degradation by homogenizing the landscape mosaic (McCullough et al. 1998).

While beneficial use of fire is no longer illegal for fire management agencies today, its use is relatively insignificant compared to the area burned by wildfires. However, there is growing interest in re-establishing cultural fire practices. In BC, for example, less than 10,000 ha is prescribed burned annually, and little of that occurs in hemiboreal and boreal ecosystems. Instead, most prescribed burning occurs in dry and mesic temperate mixed conifer forests. Cultural burning is relegated to Indigenous reserve lands rather than across traditional territories and is confined to small areas (Hoffman et al. 2022).

MAJOR ECOCULTURAL SYSTEMS

EASTERN BOREAL FORESTS

The eastern boreal forest region is characterized by strong climatic gradients, with wetter climates in Newfoundland and eastern Quebec due to the influence of the Atlantic Ocean. The climate transitions to more mesic and sometimes dry conditions in the western part of the region, except in the James Bay lowlands of northern Ontario. The contrast between the eastern and western parts of the region is reflected in the wildfire regimes, with significantly lower fire frequencies in the east (Remy et al. 2017). There is also a south-to-north contrast in the wildfire regime. Numerous small-to-medium size fires are more characteristic in the south, and periodic large fires more characteristic in the north (Bergeron et al. 2004).

In the southern part of the eastern boreal forest, insect outbreaks affect even more area than wildfire. The two most influential insects occurring in outbreaks are the eastern spruce budworm, affecting balsam fir, black spruce, and white spruce (Bouchard et al. 2007), and the forest tent caterpillar, affecting poplar and many other broadleaf species (Moulinier et al. 2013). In the far eastern portion of the region, fire and insect outbreaks are rarer and forest stands are mostly affected by windthrow (Waldron et al. 2013).

The region is bound by the tundra in the north and temperate broadleaf or mixedwood forests in the south. Black spruce is by far the most abundant species, found in early to late successional stands, as well as on a wide range of edaphic and topographic conditions. Jack pine is also characteristic of the eastern boreal forest, occurring mostly on drier sites (e.g., eskers, sand plains, and rock outcrops) and in areas of high fire frequency in the west (Asselin et al. 2003), whereas white spruce is more abundant in the eastern part of this subregion (Payette 2007).

Balsam fir, a late-successional species, mostly occurs on mesic sites. Broadleaf tree species are found in the southern portion of the eastern boreal forest. Quaking aspen and paper birch are common early successional hardwood species dominating recently burned or clearcut logged sites. Except for balsam fir, all aforementioned species are adapted to moderately frequent fire (< 50 years). Understory composition is dominated by mosses and/or lichens at ground level, ericaceous shrubs (members of the heather family like blueberries, Labrador tea, Azaleas, rhododendrons), willows, and alders. An important proportion of the zone is covered in peatlands, mainly areas with perched and regional bogs, and fens, that support varying amounts of tree cover.

From the south to the north, eastern boreal forests become sparser (Payette et al. 2001). Forests north of the commercial forest limit are dominated by conifers (mostly black spruce and jack pine, Figure 2). They exhibit much lower productivity and are often called woodlands (Jobidon et al. 2015). Lacking any evidence of industrial forestry, the northern boreal forests of eastern Canada contain some of the last remaining large expanses of intact old boreal forests in North America. They are also more sensitive to wildfire disturbance and climate variations than more southerly boreal forests (Oris et al. 2014). Old eastern boreal coniferous forests are home to emblematic wildlife species such as the American marten and the endangered woodland caribou. Other wildlife species observed across a wide range of forest types and successional conditions include moose, black bear, wolves, snowshoe hare, beaver, and ruffed grouse.

Figure 2. A boreal forest in *Eeyou Istchee* (western Quebec). Photo credit Guillaume Proulx.

The eastern boreal forest region is also characterized by its low human population density, distance from metropolitan and central government office centers, high dependence on extractive industry-related employment, and overall poor socio-economic conditions (Stedman et al. 2005). The region is comprised of the traditional lands of Mi'kmaq, Innu, Naskapi, Cree, Atikamekw, and Anishnaabe peoples, all of which are members of the Algonquian language group. Historically semi-nomadic people, they now reside in villages and communities following forced settlement to small reserves in the 19th and 20th centuries. Members, however, still conduct cultural activities on traditional lands, including hunting, trapping, fishing, gathering of edible and medicinal plants, knowledge transmission, and spiritual and healing activities (Bélisle et al. 2021). Land uses by these Indigenous Peoples over millennia forged cultural landscapes with their needs, people, and traditional lifeways intimately interwoven with the landscape. Today, these cultural landscapes are sorely lacking in these cultural connections and their distributed effects, and the original people have been mostly denied these traditional lifeways (Davidson-Hunt & Berkes 2003).

WESTERN BOREAL FORESTS

The Na-Dene or western boreal forest region extends from the Pacific and Arctic coasts of North America to the west coast of Hudson's Bay. This vast region is broadly divided here into: (1) the interior western region, (2) the interior cordillera forests, and (3) the central valleys and coastal Alaska and the Yukon. The boundary between the interior west and cordillera subregions is the Dehcho (Mackenzie River). To the west of these subregions lie the central valleys and coastal Alaska and the Yukon, where forests occur in interior Alaska and in coastal areas north of 60° latitude.

The topography of the interior west is flat to undulating, with several high plateaus, whereas the interior cordillera and Alaska/Yukon central valleys and coastal forests are composed of multiple mountain ranges. Permafrost, or permanently frozen soil, is continuous in northern forests and mountain areas south of the arctic treeline (subarctic region), discontinuous (underlying 10 - 90% of the landscape) south of this region, and largely absent south of 60° latitude (Obu et al. 2019).

Peatland complexes and waterbodies are an important feature of this region, with peatland formation driven by surficial geology (Wieder et al. 2006). The western boreal forest region has some of the highest fire frequencies in North America (Kasischke & Turetsky 2006). Together, peatland complexes, waterbodies, and large river systems break up the landscape to limit fire spread, while concurrently facilitating both historical and modern human travel.

The western boreal forest region is bound by the tundra in the north and at high mountain elevations, in the south by grasslands in the heart of the continent, and by temperate conifer forests near the Pacific coast. Interior forests are characterized by low-productivity stands dominated by black spruce, white spruce, jack pine, lodgepole pine, and eastern larch, with a regionally important broadleaf component composed mainly of aspen, black cottonwood, and birch. Further south, where the region meets the eastern and central boreal forest regions and the Rocky Mountains, mixedwood forests predominate, with poplars and birches becoming increasingly common. North of this region, forests give way to arctic tundra.

Treeline forests are generally low-density, open spruce forests. A similar mix of species are found in the interior cordillera, with the addition of the occasionally dominant subalpine fir in high-elevation areas. Productive forests are confined to the valley bottoms in the southern part of the zone, and forest cover is increasingly sparse at high elevation and in northern areas. The coastal and interior central valleys of Alaska and the Yukon also have a similar tree-species assemblage, with the notable exclusion of pine species throughout the area, and locally dominant Alaska paper birch found in the coldest, wettest locations, with black spruce. Forest understories across this region are dominated by willow, huckleberry, crowberry and other small shrubs, and moss, liverwort, and lichens.

Recurrent fire is common in upland forests throughout western boreal zone, with mean return intervals of 50-150 years (Dyrness et al. 1986). Burned area, which is largely driven by climate (Young et al. 2017), created a patchwork of stands with different time-since-fire conditions. This wildfire-driven heterogeneity interacts with the variation caused by topoedaphic factors (Burton et al. 2008). Many mature and old forests are mostly confined to peatlands, islands, and features of topographic relief often associated with mountains, ridges, deep valleys, and riverbeds (Stralberg et al. 2020). Aggressive fire suppression and land-use change have reduced burn area near human communities, but human impacts on fire dynamics are low, overall, relative to more southerly biomes (Parisien et al. 2020). Temperatures are rising more than twice as quickly as in temperate latitudes (Ballinger et al. 2023), resulting in decreased snowfall and spring snow water equivalent (Ballinger et al. 2023; Littell et al. 2018), increased temperature-driven water deficit (Li et al. 2022), and warmer, longer fire seasons. Increasing fire frequency is leading to a shift toward broadleaf species dominance, reduced conifer land cover (Mann et al. 2012), and more frequent ground fires in moss and organic surface soil layers that can smolder for months or years (Scholten et al. 2021). Insect outbreaks—some unobserved in previous decades—are increasing, such as the spruce bark beetle, whose rapid expansion in the 1990s and again since 2015 has caused extensive white spruce mortality in forests south of the Alaska Range.

SOUTHERN CANADIAN ROCKIES AND NORTHERN US ROCKIES (HEMIBOREAL)

The southern Canadian Rocky Mountains represent a transition area between boreal forests to the north and temperate forests and prairie grasslands to the south. The area is part of the greater band of hemiboreal vegetation that comprises the southern fringe of the boreal biome, integrating ecological elements from various vegetation systems across the continent. The rugged Rocky Mountains, combined with the increasing input of moist-warm air from the Pacific, create strong climatic gradients leading to diverse vegetation types and associated disturbance regimes.

Forests of this region are characterized by dense lodgepole pine and Engelmann spruce in hemiboreal forests, a naturally occurring Engelmann-white spruce hybrid in the north, and subalpine fir and quaking aspen, and mixes of these depending upon disturbance histories. High-elevation forests below the upper treeline support whitebark pine, limber pine, and subalpine larch. In the western and southern portions of the region are temperate mixed-conifer forests of Douglas-fir, western larch, and lodgepole pine in low and mid-elevations, interior western hemlock and western redcedar in the deep Rocky Mountain Trench that separates the Rocky and Columbia Mountains, and aspen, lodgepole pine, and spruce parklands to the east of the mountains.

Across large areas, the historical landscapes were characterized as a rich patchwork mosaic of different forest and nonforest communities, structures, open and closed canopies, varied seral stages, and patch sizes. Many lines of evidence support this characterization, including Indigenous oral histories, ethnobotanical and anthropological studies, historical stand and landscape reconstructions, fire history, and repeat photography analyses (Kubian 2013; Mah 2000; McCaffrey & Hopkinson 2020). Early seral forests, grasslands, sparsely treed woodlands, and shrublands occupied 30-50% of the landscape area over time owing to widespread cultural burning, lightning ignitions, and broad variation in the regional climate. The diversity of vegetation and fuel conditions limited future fire size and severity.

Indigenous Peoples of this southern Rocky Mountain region used a wide array of material, medicinal, and food resources to sustain them across a large traditional territory, which included parts of eastern Washington, Idaho, and Montana. Seasonal activities included root and berry gathering, hunting for deer, elk, moose, bear, and mountain goat, brush clearing, trail maintenance, fishing for cold water and anadromous fish, and hunting for upland birds and waterfowl (“Kutenai Language Task Force” 1989). Bison were hunted in the Plains region east of the Rockies.

CONTEMPORARY AND EMERGING THREATS

Rapidly changing fire regimes represent the primary broad-scale threat to old and other forests of the boreal/hemiboreal region. Fire activity, particularly area burned, has increased in recent decades in parts of the boreal forest (Hanes et al. 2019; Kelly et al. 2013). Future projections strongly suggest fire activity will increase in response to warming throughout the region (Boulanger et al. 2014; Wang et al. 2020). Patterns are highly regional both in space and time, and some regions have not yet undergone observable changes despite an increased potential (Gaboriau et al. 2023). Despite these recent increases, dendrochronological evidence suggests that parts of the boreal zone historically burned more frequently than it currently does (Chavardès et al. 2022), offering insight into the alarming capacity for future increases in fire frequency. For instance, the relative lack of wildfire activity in the eastern boreal zone during the last few decades, relative to the western part of the biome, resulted in a greater continuity of flammable fuels. This increase in fuels contributed to the record-breaking fire activity during the 2023 wildfire season, where about 4 million ha burned in the province of Quebec alone. This event, as well as other extreme wildfire seasons, have been attributed to the changing climate (Barnes et al. 2023; Kirchmier-Young et al. 2018), and are part of a broader biome-wide increase in wildfire activity over the last half-century (Sierra-Hernández et al. 2022; Whitman et al. 2022).

Increasing fire frequency and severity in boreal and hemiboreal regions is contributing to a biome-wide shift toward broadleaf trees and fast-growing species such as jack pine, and the decline of late-successional conifer species and old forests (Baltzer et al. 2021; Searle & Chen 2017b). Where severe short-interval reburns arise, without adequate time for seed banks to replenish between fires, vegetation-type conversions from forest to shrubland or savanna ecosystems result (Brown & Johnstone 2012; Hayes & Buma 2021; Whitman et al. 2019). Areas that have undergone fire-mediated forest loss and species dominance changes have generally failed to return to a composition and structure like that prior to fire, suggesting these changes are persistent (Asselin et al. 2006; Walker et al. 2023). Climate-driven advances in the treeline have been limited and variable (Timoney & Mamet 2019; Trant & Hermanutz 2014), and do not compensate for fire-mediated forest loss (Burrell et al. 2024; Timoney et al. 2019).

Paradoxically, in some areas, fire exclusion and climate-mediated declines in fire have contributed to a loss of landscape heterogeneity (e.g., declining high-latitude grasslands; Schwarz & Wein 1997), and a preponderance of mature conifer forests in some regions (e.g., hemiboreal northern Rocky Mountains). Where fuel buildup has occurred, fire severity and size now exceed the historical fire regime conditions to which trees were adapted. Forests with unique topoedaphic settings that shelter them from fire (fire refugia), through terrain or hydrological constraints on fire spread, are key seed sources for burned forests and important residual habitat (Ouarmim et al. 2015; Rogeau et al. 2018). Climate change and fire suppression have increasingly place these sites at risk to fire, as their capacity to act as natural firebreaks is exceeded by weather or fuel connectivity (Krawchuk et al. 2016; Mackey et al. 2021). Severe wildfire in forests that have experienced a fire deficit may negatively affect mature and old growth forests where the fuel structure has been substantially altered.

Increasing temperatures will likely lead to more extensive, severe, and long-duration forest insect outbreaks in mature and old growth boreal forests (Volney & Fleming 2000). For example, the spruce bark beetle epidemic of the 1990s and early 2000s in southeastern Alaska and southwestern Yukon Territory killed as much as 40% of mature white spruce in some regions. In interior British Columbia, warmer winters and increased continuity of mature pine forests due to fire suppression and forestry practices led to a vast (approx. 20-25 MM ha) mountain pine beetle (MPB) outbreak in the 1990s and 2000s. Insects have begun to extend their ranges in direct response to climate warming. For example, mountain pine beetles have crossed the Rocky Mountains into the southwestern boreal forests of Alberta, attacking both lodgepole pine-jack pine hybrid stands and pure jack pine stands. The possibility of widespread eastward expansion of MPB constitutes a major threat to extant boreal forests (Safranyik et al. 2010). Similarly, the western spruce budworm, a native defoliating insect that attacks spruce, true firs, and Douglas-fir, is expanding its range due to warming temperatures and drought

Figure 3. High severity burn patch in a hemiboreal forest in Canada. Photo credit Diana Stralberg.

(Navarro et al. 2018; Pureswaran et al. 2015).

Warming temperature and drought stress also directly affect forest productivity and health. Severe droughts have caused extensive areas of aspen dieback (Michaelian et al. 2011; Worrall et al. 2013). Climate change-associated moisture stress creates pervasive declines in forest biomass and growth in both uplands and wetlands (Michaelian et al. 2011; Searle & Chen 2017a) and has been implicated in poor post-fire seedling establishment and regeneration (Boucher et al. 2020). Climate warming has led to permafrost thawing, with fire acting as a catalyst that accelerates this process (Gibson et al. 2018). In areas underlain by permafrost, thawed permafrost-slumps, sudden changes to water table depths, and overland flow as a result of altered surface water availability often lead to "drunken forests" (those areas with unstable and tilting or tipped over trees), flooding and tree mortality due to high water tables, and direct forest losses from slope instability (Gibson et al. 2021; Helbig et al. 2016). The future dynamics of forests underlain by permafrost are poorly understood, with a possibility for interactions or feedbacks creating highly unstable or unpredictable long-term ecological changes and losses of soil carbon.

Many lowland forests are typified by deep organic soils across the boreal/hemiboreal zone that are peat forming. Peatlands are somewhat protected against fire due to the moist conditions associated with these soils. However, climate change is causing longer, drier fire seasons leading to peatland fires during summer months. These peat fires result in smoldering ground fires that can burn for extended periods, lasting months to years, and releasing enormous amounts of carbon from peatland derived soils (Turetsky et al. 2015). When burning under increasingly droughty conditions and with increasing frequency, peatland 'legacy carbon' held in storage for hundreds to thousands of years is combusted and emitted as a source of greenhouse gas (Walker et al. 2019), a phenomenon further exacerbated by the probable increase in overwintering wildfires (Scholten et al. 2021). Increases in peat burning in boreal forests has the potential to provide a large and increasing positive feedback to climate change, by releasing this legacy carbon and creating methane emissions by accelerated permafrost thaw. Upland soils are also sensitive to changing disturbance regimes and drying conditions, both factors contributing to a shift in understory and ground layer species composition. The ubiquitous feather moss is particularly sensitive (Paquette et al. 2016). These changes directly affect long-term productivity of these forests, given their relatively shallow soils, low fertility, and low productivity (DeLuca et al. 2002; Turetsky et al. 2010).

The confluence of multiple factors, including fire exclusion, insect outbreaks, and climate change, has left the forested landscapes of the boreal and hemiboreal region highly vulnerable to an uncharacteristic scale increase of high-severity fire (Figure 3). Widespread changes and mounting threats to boreal forests presented here will likely interact with human development and wildfires to create cumulative effects on continental scale forest health and sustainability (Venier et al. 2014). Ongoing changes to wildfire regimes in boreal North America have the capacity to dramatically alter the health and viability of mature forests, with serious direct and indirect negative effects on the health and well-being of people (Dodd et al. 2018; Gibson et al. 2021; Reisen et al. 2015; Spring et al. 2019). The path forward includes an understanding of the role and magnitude of influence of anthropogenic climate change, and the importance of forecasting cumulative threats today and into the future.

PLACE-BASED EXAMPLES

Curbing the loss of old forests from large, high-intensity wildfires in northern Rockies landscapes

Wildfire risk reduction in cultural northern Québec landscapes

EASTERN TEMPERATE FORESTS

GEOGRAPHY AND CLIMATE

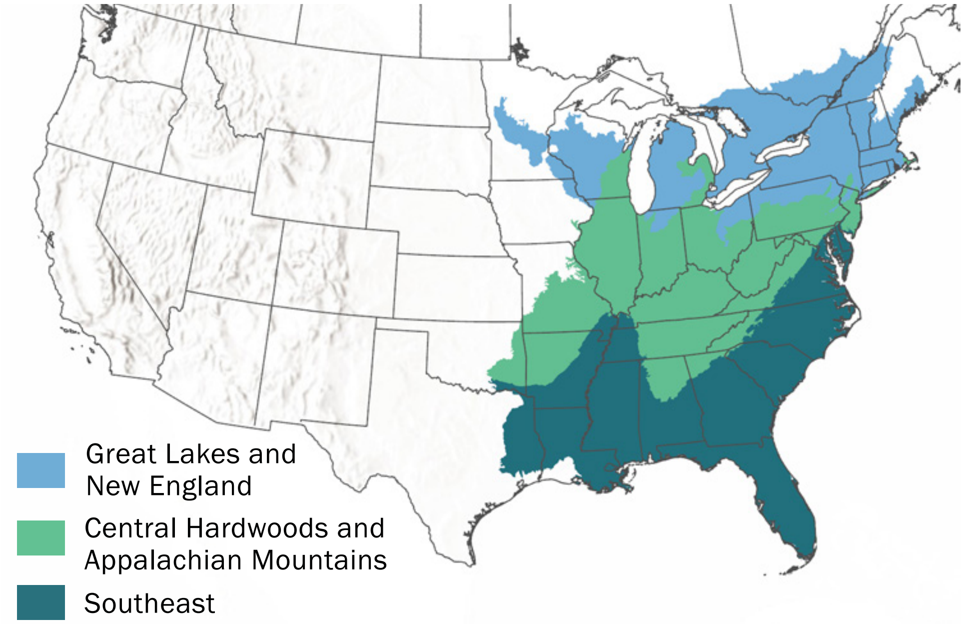

Figure 4. Extent and major regions within the Eastern temperate forest zone.

Eastern temperate forests (Figure 4) span a broad range of cultures and ecosystems. The region is humid with greater mean annual precipitation than many interior western temperate and boreal forests (Figure 5). Eastern temperate forests are also typified by high plant and animal diversity.

The Southeastern pine-oak region spans the Atlantic and Gulf Coastal Plains from eastern Texas to coastal New England, the Piedmont from Alabama to the Delaware Peninsula, and the Black Belt from Tennessee to Georgia (Omernik & Griffith 2014). The region abuts the interior highlands and Texas scrub oak region to the West, and the Ridge and Valley region to the north along the eastern seaboard. The climate of this region ranges from warm, subtropical – with strong marine influence – to cool, continental and temperate, with distinct seasons and snowfall. The Coastal Plain is a broad arc spanning the coastal side of this pine-oak region. The Coastal Plain has subtle relief in the uplands, broken by the Lower Mississippi Alluvial Valley ("the Delta") and bottomland hardwood forests along major rivers that incise the region. The wooded uplands are dominated by temperate and subtropical savannas, woodlands, and forests of pine and oak that are the primary examples of the region's ecocultural systems. Peninsular Florida's open pine rocklands, dense pine-oak scrubs, and intermingled wetlands are globally unique landscapes.

Central Hardwood and Appalachian forests span a large area of the eastern United States located south of New England to the Great Lakes, east of the expansive Great Plains, and north of the Coastal Plain and Piedmont regions. The region encompasses unglaciated landscapes and the complex mid- to high-elevation topography of the Appalachian Mountains in the east, and the Ozark, Boston, and Ouachita Mountains in the west. The climate of the region is warm and continental with increasing annual precipitation along a northwest to southeast gradient.

The Great Lakes and New England regions are diverse landscapes encompassing multiple ecosystems and important transitional vegetation zones. This region stretches from western Minnesota to Maine, and south to New Jersey, including nearly nine degrees of latitude north to south. The region is bordered on the west by the Great Plains, the south by the Central Hardwoods and Appalachians and on the east by the Atlantic Ocean. Landscapes were shaped by repeated glaciations, with the most recent glacial period ending about 20,000 years ago, although more minor advances and retreats continued until ~10,000 years ago (Larson & Schaetzl 2001). Glacial drift and extensive glacial till dominate many parts of the landscape. Glacial till intermixed with areas of exposed bedrock are found along the northern limits of the region. Extensive glacial outwash plains are present with more northerly regions containing glacial depositional features including morainic ridges, drumlin fields, and other features related to glacial activity. On the southern margins, unglaciated areas are characterized by deeply eroded valleys and ridges.

The climate of the Great Lakes and New England is characterized by cold winters and warm summers, with precipitation relatively evenly distributed throughout the year both spatially and temporally, although shorter-term seasonal droughts occur within the general precipitation patterns. Precipitation decreases along a longitudinal gradient from east to west while a latitudinal gradient in temperature patterns leads to gradual transitions between near-boreal forests in more northerly locations to hardwood forests in

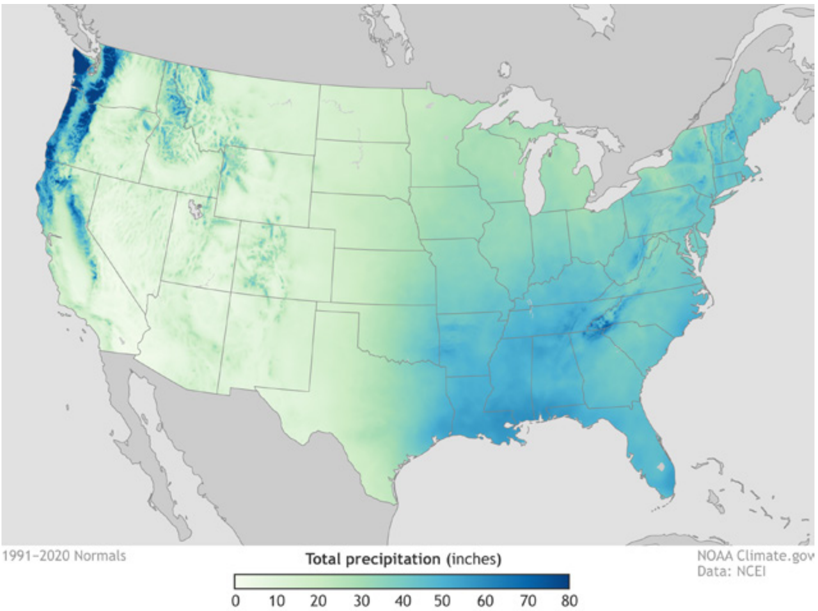

Figure 5. Mean annual precipitation (1991-2020) for the conterminous United States. Photo credit NOAA / climate.gov.

more central and southerly locations. The west to east increase in precipitation across the region is at least partly due to the advection of warm humid air masses northeastward into the region from the Gulf of Mexico. This broad zone, which is transitional between the central hardwoods to the south and the boreal forests to the north, has been described as the North Woods. Together, these principal environmental gradients in water availability and solar energy lead to transitional landscapes supporting an array of vegetation and associated fire regimes. Locally, the influence of the Great Lakes moderates temperature patterns while enhancing winter-time lake-effect snowfall extending from the western Great Lakes to the eastern shores of Lake Erie in northeastern New York.

CLIMATE ADAPTATION STRATEGIES

Euro-American colonization started in the eastern US and Canada as did the first industrial logging, intensive colonist agricultural systems, and urban centers. Hence, human population density and associated ecological impacts are generally greater in these ecocultural systems. Owing to the longer history of Euro-American colonization, this broad region experienced the earliest consequences of Indigenous decimation and displacement, including the cessation of Indigenous land stewardship and the loss of Indigenous Knowledge (IK) of cultural stewardship practices in most places. Nevertheless, forests have displayed remarkable resilience in the face of historical pressures, including widespread clearcutting (much of the Eastern, Southeastern, and Midwestern forests were cut over in a fairly brief period), conversion to agriculture and forest fragmentation, the introduction of numerous pests and pathogens via global trade, and the loss of place-based Indigenous stewardship. Moreover, climate change is expected to severely stress these forests, and extensive, place-based climate adaptation will be required to maintain forest health and resilience (Table 2).

Given the broad diversity of forest types, ownerships, and the multiple threats across the Eastern temperate region, climate adaptation strategies will require strong place-based scenario planning and coordination. Forested landscapes are highly fragmented and primarily held in private ownership (Ritters et al. 2012). Supporting Tribal and Indigenous land return, public land conservation purchases, development of conservation easements to maintain high quality private lands, and prioritizing restoration of degraded ecosystems can support ecocultural restoration throughout the region. Strong collaborations across ownerships also are needed to prioritize resilience via connected, fire and climate change adapted forest habitats that promote genetic and biological diversity (Hamilton et al. 2022).

A Two-Eyed Seeing approach, combining Indigenous Knowledge (IK) and Western Science (WS), is paramount for developing effective climate mitigation strategies to address the broad range of threats to forest health and resilience. Preparing for and adapting to climate change is perhaps the best example of the need for a Two-Eyed Seeing approach. Western Science can deliver powerful tools for forecasting future climates and their potential effects on mature and old forests (Lucash et al. 2017; Robbins et al. 2024), and Indigenous Knowledge can provide deep insight into how these challenges have been met in the past and place-based management trials that can be used when certainty of outcomes is in short supply.

The Fifth National Climate Assessment (USGCRP 2023) clearly outlines how changing climate is impacting the region. A warming climate will push plant and animal species outside of their climatic niche as seasonal temperature and precipitation relations change. Precipitation will generally not keep up with increasing temperature—reducing soil moisture on average—with cascading impacts across all seasons. Regional drying trends are both increasing the potential for severe wildfire seasons (Robbins et al. 2024) and reducing the window of opportunity for safely applying prescribed fire (Kupfer et al. 2020; Lucash et al. 2022). Even though summer growing seasons throughout eastern North America are generally humid with significant rainfall, the potential for destructive droughts is increasing (Au et al. 2020). Warming will also alter host-pathogen and host-insect relationships of many native tree species and shift their phenology (e.g., the timing of their flowering, leafing, overwintering, reproduction, and dispersal). These phenological shifts also have consequences for animal and insect species that forage on plants. These changes to climatic regimes are geographically uneven, with coastal areas experiencing changes that differ from inland and continental regions, requiring place-based adaptive management approaches.

The significant potential of high-wind events to severely impact forests uniquely threatens eastern forests. If Atlantic tropical cyclones (Elsner et al. 2008; Gilliam 2021; Webster et al. 2005; Lasher-Trapp et al. 2023; Prein 2023) increase in frequency and severity, planning actions for adapting damaged and departed ecosystems to this altered disturbance regime will be necessary to both minimize further damage and to hasten ecocultural restoration (Mitchell 2013; Gardiner & Quine 2000). More specifically, with more wind-driven disturbances under climate change, it is necessary to develop and implement regional recovery plans to mitigate subsequent fire and insect mortality and risk from hasty salvage operations after the wind events. Such plans can include necessary actions for rapid deployment of post-disturbance restoration removals of blowdown and damaged trees and reforestation to climate- and fire-adapted species and densities.

OAK AND PINE FORESTS AND WOODLANDS

To adapt the pine- and oak-dominated communities to climate change and its influences of shifting fire regimes, it is critical to greatly expand the use of cultural and prescribed burning and allow for more rather than less flexibility in the timing, application, and severity of the fires that are allowed. Intentional understory burning is used to restore and maintain open canopy, fire-dependent conifer and oak communities, reduce encroachment by fire-intolerant hardwoods, and promote herbaceous species diversity (Arthur et al. 2021). While the use of prescribed and cultural fires can be challenging, our understanding of regional fire regimes coupled with advances in fire science more broadly, has led to outcomes with demonstrated effectiveness (Vander Yacht et al. 2019). In contrast to the remainder of the US, the southeastern US has many examples of ecosystems with intact fire regimes (Ryan et al. 2013). Enabling widespread use of fire use will assist in both maintaining fire-adapted ecosystems and in supporting ecocultural restoration.

Where oak and pine assemblages exist, it will be increasingly important to re-emphasize the expanded ecological importance of open forest and woodland structural conditions occupied by fire tolerant native species and avoid maladaptive afforestation and reforestation as climate change mitigation strategies (Veldman et al. 2019). As in the midwestern and western US, grasslands, balds, savannas and woodlands are critical elements of resilient and climate-adapted forest landscapes and were historically widespread and fire-maintained (Hanberry and Abrams 2018).

Historically, many pine and oak forests and woodlands were multi-cohort in their size and age class distributions (Flatley et al. 2023; Platt et al. 1988; Stambaugh et al. 2014). Planting for drought and wind resistance after tree harvests and major windstorms, and maintaining multi-cohort stands, will improve resilience to wind damage (Bigelow et al. 2021; Polinko et al. 2022). Moreover, with the coming changes in climate, planting zones for fire-adapted species will shift as well. Experimental planting of broader seed zone collections in planting stock and re-investment in provenance trials will aid in the deployment of diverse genetic stock with greater opportunities for adaptation to the coming climate and disturbance regime changes.

MIXED HARDWOOD AND CONIFER FORESTS

The multiple threats faced by mixed hardwood and conifer forests of the Eastern Temperate region are rapidly and severely impacting forests (Rustad et al. 2012). Following the functional extirpation of American chestnut in the 20th century, nonnative insects and pathogens are now causing widespread mortality of keystone species including eastern hemlock, American ash, and yellow beech and profound changes in forest structure, composition, and function (Barton & Keeton 2005). Tree health and mortality associated with drought, forest insects, and pathogens will require continuous monitoring–both locally and via remote sensing (Boucher et al. 2021). Responses to rapid and profound changes in forest structure and

Table 2. Adaptation toolbox for protecting and restoring eastern temperate forests.

Adaptation strategy	Description	Ecocultural system(s)	Threat(s) addressed
Beneficial fire, surface fire	Frequent cultural and prescribed understory burning	Pine and oak woodlands, forests	Encroachment and mesophication by mesic hardwoods, loss of culturally important understory species and fire adapted habitat.
Adaptive silviculture	Group and individual tree selection to promote climate-adapted species and accelerate forest development	Pine and oak forests, mixed hardwood forests	Rapid change in forest structure, composition and function from multiple agents including drought, extreme wind events, fire exclusion, and invasive insects and pathogens.
Dynamic protected areas	Creating an interconnected system of protected areas that conserve forests and allow for ecocultural restoration and stewardship	All	Forest clearing and development
Reforestation and adaptive planting trials	Restoration of understory plant assemblages, post-disturbance recovery, and experimental tree planting	All	Severe wildfires and hurricane damage, climate change
Increase tree diversity and age classes	Silviculture that promotes greater species and age diversity promotes resilience to climate and disturbance changes	All	Rapid change in forest structure, composition and function from multiple agents including drought, fire (exclusion, high severity), and invasive insects and pathogens.
Invasive species detection and monitoring	Treat and monitor invasive species	All	Loss of biodiversity and ecosystem services due to invasive species dominance over native flora and fauna

composition will require active cultural stewardship applying Indigenous Knowledge, Western interventions such as introducing biological control agents (parasites, pathogens, and predators on nonnative species acquired from their ancestral homeland) or genetically engineered resistance, and application of targeted pesticides, herbicides, and silvicides (*Climate Adaptation Plan* 2022). Active planting of tree species in areas that will be more climate-suitable for them in the future (i.e., assisted migration) may help to reforest landscapes where longer term stability is a goal (Duveneck & Scheller 2015).

Where forests are highly degraded, restoration may initially be necessary to reconstruct forest structure, composition, processes, and forest health, including the removal of some mesophytic species, favoring or planting other species, and the direct manipulation of forest structure. In other cases, the restoration of biodiversity may be sufficient, such as under-planting extirpated or underrepresented species. With further advances in breeding and genetic tools, managers will continue replacing lost keystone species (e.g., Gilland & McCarthy 2012; Westbrook et al. 2020).

At the broad regional landscape-scale, limiting the growth of WUI (building up rather than out) and allowing native plants and animals to more freely migrate and disperse into climate-suitable settings can reduce some effects of fragmentation. Climate adaptation will also necessitate restoration of more dynamic landscapes that are capable of supporting the range of forest types that previously existed, while being cognizant of potential climate futures, altered disturbance regimes, and existing settlement patterns.

Successful climate adaptation requires an Indigenous mindset of continual observation, intervention, practice, and experimentation, a land ethic of reciprocal stewardship, and local decision-making. Proactive stewardship emphasizing the Seven Generation Principle in lieu of compliance to rigid planning is necessary and will require a coordinated effort to reach a diversity of landowners. Through respectful engagement and formal co-stewardship partnerships, there are numerous Tribal Nations that could lead and inform the practice of active cultural stewardship. Paired with the extension programs provided by public universities, a systematic rethinking and reframing of forest stewardship is possible, and it will require long-term investments steeped in learning and doing. Public land managers have the opportunity to accelerate and amplify these efforts by applying IK and WS within national forests, parks, and preserves and by crafting policies emphasizing these values.

PLACE-BASED EXAMPLES

Ecocultural Restoration in Pine-Hardwood Forests of the Menominee Tribe

Structural Complexity Enhancement at Stevensville Brook Research Area

Red Hills Conservation Lands

SOUTHEASTERN FORESTS

Lead Authors: J.M. Varner, N. Zampieri, L.N. Kobziar, and M.C. Stambaugh

The Indigenous Peoples and landscapes of the Southeastern Coastal Plain, Piedmont, and Black Belt, like much of the US, have suffered grave injustices. Genocide, the introduction of human diseases for which there was no acquired resistance or immunity, displacement to distant reservations, and intentional cultural marginalization have all led to diminishment of these once highly active and thriving cultures. Still, strong ecocultural systems remain, and there is a cultural renaissance among many Tribal Nations to implement and relearn many of their traditional cultural stewardship practices and lifeways.

It has been centuries since the devastating European influence on eastern Tribal Nations. With the centuries-long attempted erasure of once widespread stewardship practices, much place-based knowledge has been lost or forgotten and Indigenous stewardship of eastern landscapes has dwindled. However, there is abundant evidence that Indigenous Peoples used fire extensively as part of their ongoing relationship with this landscape. Place-based IK and practice continue in some areas with local Tribes and Indigenous Peoples. Historical accounts of Indigenous burning practices identify the use of fire for as long as people have been present in the region. Fire was widely and frequently used to clear for agricultural and game hunting purposes, to enhance habitat, increase forage, reduce fuel loads and the pests of oaks and acorns, to protect settlements from wildfire, to cultivate basketry materials, and to maintain open landscapes for travel corridors and hunting (Anderson & Sassaman 1996; Jones 2014; Pyne et al. 1996; Van Lear et al. 2005). To meet a variety of seasonally-related goals, Indigenous burning occurred in all seasons (Delcourt & Delcourt 1997; Pyne 1997; Van Lear et al. 2005; Williams 1992a). Over many millennia, combined lightning and human-ignited fire shaped landscape structure, function, and composition.

MAJOR ECOCULTURAL SYSTEMS

The primary forested ecocultural systems in this region range from oak, mixed oak-pine, to pine-dominated open savannas and woodlands (Figure 6). Embedded within these are other ecosystems that vary from grasslands and prairies to closed canopy mixed hardwood forests. Diversity in structure and processes within these ecosystems was cultivated through exposure to disturbances and interactions with environmental conditions. Primary disturbances include frequent fire and large-scale wind events associated with recurrent Atlantic tropical hurricanes and intense cyclonic winds below hurricane strength.

Fire regimes vary widely from the uplands to the wetlands, with strong signatures of Indigenous and other anthropogenic burning across the wide region. Upland pine ecosystems have some of the most frequent fire return intervals in North America, with historical return intervals of 1-3 years, and evidence for biannual burning in some instances (Rother et al. 2020; Stambaugh et al. 2017). Here, the pine needle and oak litter, seasonal precipitation, and productive grassy herbaceous understories work together to promote the spread of frequent fire across the landscape. Much of the region supports long growing and fire seasons.

Plant and animal diversity is among the highest found anywhere in North America. Frequent fire is a major contributing factor to that diversity as it maintains open, light-filled forest canopies and understories. The region contains over 1,500 endemic plant species and the highest taxonomic diversity of vascular plant families (150+) and tree species diversity in the contiguous US (Kartesz 2015). Amphibians and reptiles also share incredible species richness and endemism in the region with 120 known species of amphibians and 290 species of reptiles, of which approximately 40% are endemic (Noss et al. 2015). The ecotones, embedded wetlands, and mixed hardwood forests host an impressive tree diversity. In wetlands and mixed hardwood forests, the wet soils and closed canopies lack flammable fuels to facilitate frequent fire, though fire occasionally carries from nearby uplands in dry years.

PINE SAVANNAS AND WOODLANDS

Pine savannas and woodlands in the southeast spanned most uplands in the Coastal Plain from southeastern Virginia and west to eastern Texas during the Pre-Columbian era. Many pine savanna canopies of that era were monodominant, with longleaf pine, at times a subcanopy of xeric oaks (e.g., turkey oak, sand live oak, and blackjack oak), and a highly diverse herbaceous groundcover dominated by pyrogenic wiregrasses. Southern pine ecocultural systems burned remarkably often, with annual and intra-annual fires identified in the tree-ring fire record (Rother et al. 2020; Stambaugh et al. 2017). In poorly drained spodosols (“flatwoods”) in Florida and southern Georgia, longleaf pine, slash pine, and pond pine historically dominated these sites, with shrubs (e.g., saw-palmetto and gallberry) and a diversity of herbaceous species also present. In peninsular Florida, slash pine rockland savannas towered over herbaceous and subtropical woody taxa and burned several fires per decade (Platt 1999).

Figure 6. An old longleaf pine-dominated savanna in the Red Hills of southwestern Georgia. These ecosystems are managed with frequent prescribed fire and host tremendous plant and animal diversity. Photo credit Morgan Varner.

PINE-OAK AND MIXED HARDWOOD UPLAND FORESTS AND WOODLANDS

Upland pine-oak woodlands of the pre-Columbian era extended across the Piedmont, interior Coastal Plain, and were scattered in the Black Belt and outer Coastal Plain. Flammable upland forests and woodlands were dominated by longleaf and shortleaf pine, American chestnut, upland oaks (i.e., white oak, red oak, black oak, and scarlet oak), and mockernut hickory. Fire regimes varied throughout the Piedmont region, with fire-influenced woodlands showing return intervals similar to the nearby coastal plain. In peninsular Florida, xeric scrub forests were dominated by Ocala sand pine and a diversity of scrub oaks with a dense ericaceous shrub stratum. These scrub forests burned at low frequency, with stand-replacing fires burning once every 50 years or more (Myers & Ewel 1990). Uplands in the Black Belt were primarily grassy with diverse forbs and upland oak (e.g., blackjack oak) “domes” interspersed along ridges. The bottomlands include dominant oak species from the Coastal Plain and Piedmont areas along with green ash, sweetgum, and dwarf palmetto.

LOWLAND MIXED HARDWOOD FORESTS

Some of the Southeast's most characteristic ecocultural landscapes are the wet forests along rivers, lakes, and low wetland areas that restrict fire spread. Embedded small, isolated wetlands, pond cypress domes, cypress strands (i.e., less-favorable growing conditions occupied by stunted cypress trees), and Carolina bays (i.e., elliptical or oval depressions occurring as freshwater wetlands) dot the Coastal Plain. These wetlands result from subtle elevation differences of a few centimeters, which substantively change local hydrology and species composition. Widespread cabbage palms in the extensive lowlands of Florida historically burned with high intensity but low severity, maintaining these areas as open palm savannas. Embedded wetlands, ranging from < 1 ha to the 177,000 ha Okefenokee Swamp with carnivorous plants, bald cypress forests, and evergreen bayheads (i.e., relatively shallow wetlands and swamps that are part of a bay that is mostly remote from the larger body of water) burned in various ways dependent on their landscape position, the seasonal flammability of the vegetation, and how Indigenous Peoples stewarded the landscape.

The large riverine bottomland forests of the Coastal Plain, Black Belt, and Piedmont were some of North America's most magnificent old forests. These forests existed in largely fire-sheltered wet floodplains with diverse microtopography (e.g., levees, overflow channels, oxbows) that harbored highly variable overstory tree species. Major dominants along riparian zones included bald cypress, American sycamore, water and swamp tupelo, eastern cottonwood, loblolly pine, sugarberry, ash, bottomland oaks (e.g., overcup oak), cherrybark oak, water oak, and willow oak, sweetgum, southern Magnolia, American beech, American holly, a diversity of hickory species (e.g., water hickory, pignut hickory), and tulip-tree. Native cane was often abundant and facilitated fire spread into otherwise fire-resistant bottomlands. Fires spread from fire-prone uplands down into these sites, burning more in dry periods and less where antecedent rains dampened fire spread. Similarly, fires during dry periods likely spread into bottomlands with or without cane, likely affecting tree and other plant species composition. Many of these species resprouted after these rare fires, while larger and older trees had enough bark to survive them.

DEPARTURES IN LANDSCAPE STRUCTURE, FUNCTION, AND COMPOSITION

Contemporary forest landscapes of the pine-oak region contrast sharply with pre-Euro-American colonization landscapes. Vast upland areas have been converted to agriculture and pastureland. Many forested uplands are intensively cultivated pine plantations or are degraded old fields (i.e., agricultural lands abandoned after soil nutrients are depleted) from past unsustainable land uses and forestry practices. Today, population growth and the expansion of the wildland-urban interface continue to clear and convert southeastern forests.

Even though the South leads the US in prescribed burning (ca. 70% of all US prescribed burning is done in this region, Melvin 2020), the region still suffers from a fire deficit. Fire exclusion in the region has had widespread effects on forest structure and composition, in both frequent fire forests and those accustomed to longer fire-free intervals. In frequent fire forests, stands increased in density, particularly in small stems that would have otherwise been scalded, scorched, and consumed by frequent surface fires. Shifts in composition are even more noteworthy (Figure 7), as uplands that were often dominated by one or two pine and/or oak species dramatically increased in hardwood dominance with fire exclusion (Varner et al. 2005). Hardwoods, particularly oaks (e.g., water oak and laurel oak), sweetgum, tulip-tree, black gum, and red maple, representing the current "southern mixed hardwood forest" were once rare but are now abundant (Varner et al. 2005; Ware et al. 1993). These now closed-canopy forests dramatically reduce understory biodiversity and alter structure and processes in what were historically open, grass and pine dominated systems (Figure 8). They also alter wildland fire environments by creating more mesic understories and litter layers that are less receptive to frequent understory burning (Nowacki & Abrams 2008; Kreye et al. 2013). In forests historically characterized by longer fire return intervals, and where fire intensity and seasonality have been altered, overstory dominance of pines has been lost (Freeman & Kobziar 2011) and dewatering of the landscape by encroaching trees has altered the distribution of wetland forests across the landscape (Watts et al. 2014).

Beyond overstory vegetation changes, fire removal had cascading effects on herbaceous diversity, vertebrates, and invertebrates across these landscapes. The loss of vertebrates, particularly the endangered red-cockaded woodpecker, which is dependent on open pine forests and savannas, and a host of grassland-

Old-growth Longleaf Pine Forest
Pre Euro-American colonization

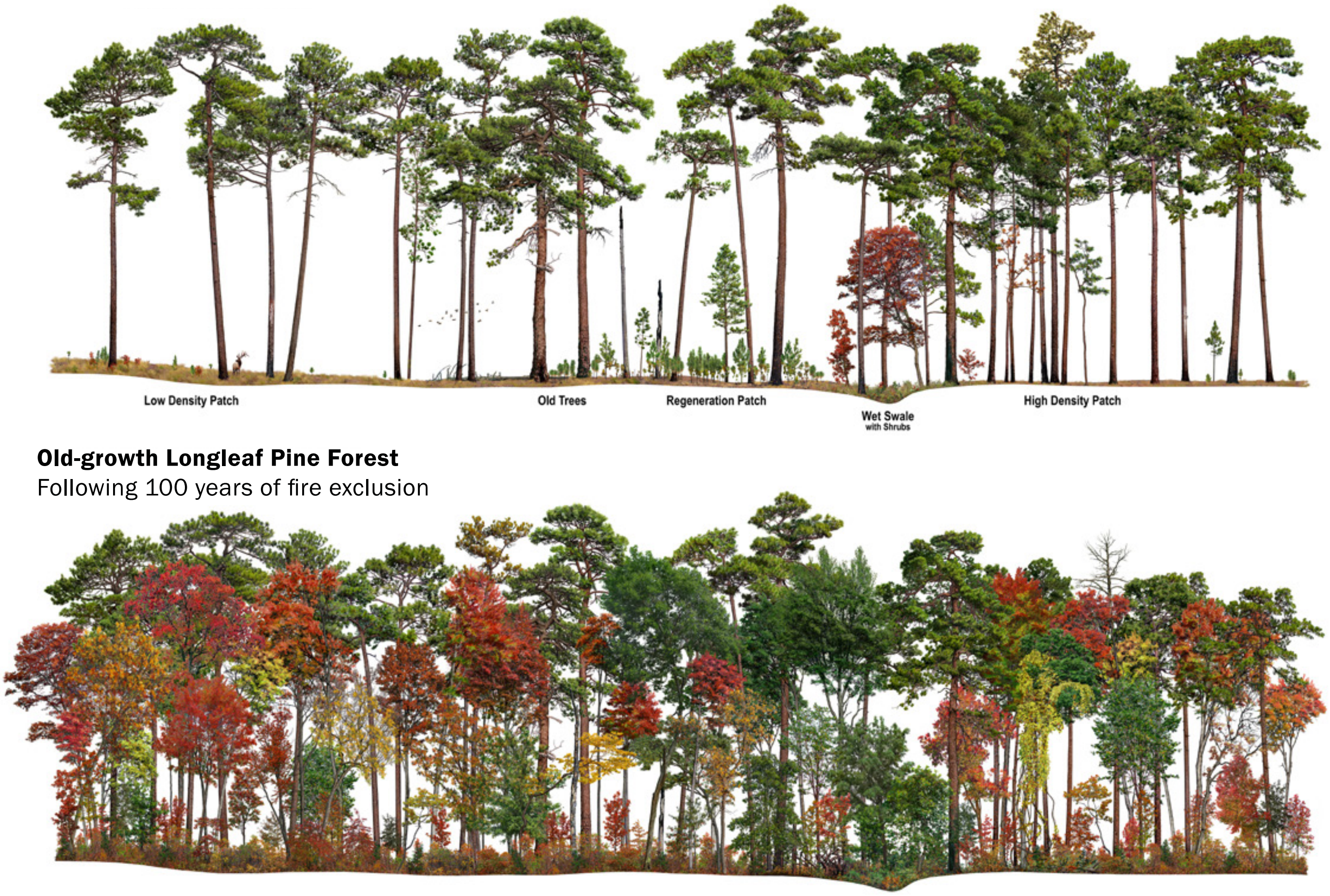

Figure 7. Side profile of an old-growth longleaf pine forest. Top panel: pre Euro-American settler colonialization. Bottom panel: hardwood encroachment following a long absence of fire. Illustration by Bob Van Pelt.

related birds, gopher tortoise, pine snakes, and Northern bobwhite quail are notable (Engstrom 1993). Invertebrates suffer from fire exclusion due to the loss of herbaceous hosts and insectivorous fauna (Ulyshen et al. 2023).

Nonnative forest pathogens have shaped current forest landscapes and will continue to do so in the future. The functional extinction of American chestnut by the nonnative chestnut blight fungus dramatically shifted forest composition in the Piedmont and more broadly throughout eastern North America (Ellison et al. 2005). Similarly, other invasive stem and needle fungi have led to the virtual extirpation of the narrow endemic Florida torreya (Smith et al. 2011). Invasions of other nonnative diseases and insects will likely continue to affect the region as they have in other eastern forests (Lovett et al. 2016).

The native grasslands of the Black Belt have suffered tremendous alteration as well, mostly in their transformation by exotic grasses to nonnative pasturelands. Elsewhere, fire suppression-driven invasion of grasslands by the native Eastern redcedar is also notable (Varner 2018). These once treeless grasslands and their associated mosaics of riparian woodlands and hilltop oak groves are now heavily invaded by this native conifer under fire exclusion. Much like wide areas of the Great Plains where this juniper is a notable invader, and similar to western interior temperate grasslands and shrublands, conifers invade and alter the ecological function and role of fire in these ecosystems where fire has long been excluded and native nonforests have been converted to forests (Varner 2018).

CONTEMPORARY AND EMERGING THREATS

The Southeastern Pine-Oak landscape is threatened by a diversity of change agents that vary in their spatial extent, severity, and interactions with other agents. Climate-driven changes in precipitation and temperature will have yet largely unknown effects on these ecosystems. However, climatic changes can have cascading effects on ecosystem structure and function by altering population dynamics, species composition, and competitive environments of overstory and understory plant communities (Zampieri & Pau 2022). Such effects may manifest through changes in plant growth rates, fire regimes, opportunities to apply prescribed and cultural fire, and the frequency and intensity of other associated abiotic disturbances. Additionally, impacts from one disturbance agent can amplify adverse impacts. For example, drought or extreme wind events can stress trees and increase susceptibility to tree-killing bark beetles, forest pathogens, and additional wind events.

Tropical cyclones are recurrent in the southeast, and are occurring with increasing frequency. Changing storm dynamics and how impacted areas are managed after events further threatens the region (Gilliam 2021). For example, high wind events influence post-disturbance species composition and structure directly via windthrow, and later with increased fuels from windthrow and wildfires. With climate change, more frequent and intense windstorms with greater precipitation are expected (Elsner et al. 2008; Emanuel 2013). Storms of increasing frequency and intensity combined with a lack of fire-maintained habitat pose a significant threat to overall ecosystem resilience of remnant upland and bottomland communities (Dale et al. 2001; Zampieri et al. 2020). Denser stands are less windfirm owing to their less well-developed and broad reaching root systems. Severe storm damage to forests, coupled with the impacts of commercially driven salvage activities, will continue to threaten once abundant and now rare old forests of the region.

The introduction and spread of nonnative plants, animals, and fungi are clear ongoing threats to southeastern forest landscapes (Ellison et al. 2005; Lovett et al. 2016). In uplands, invasion and persistence of cogon and other nonnative grasses reduce native herbaceous cover and diversity and alter the frequency and intensity of future fires. In forested wetlands and wet savannas, Chinese tallow and privet (especially Chinese privet) are two widespread woody degraders of ecosystem function, among several others that plague wet forests. Nonnative animals, including red-imported fire ants, feral hogs, and nine-banded armadillos degrade plant communities and affect native fauna. Nonnative diseases, particularly those that affect overstory tree taxa will likely continue to increase, as they have in other regions (Aukema et al. 2010).

Figure 8. Open canopy longleaf pine forest with wiregrass understory.

Given fire's critical role in ecosystems in the Southern Pine-Oak region and the effects of exclusion, there are many threats related to fire. The future structure, function, and diversity of fire-dependent pine-oak savannas and woodlands depends on the capacity to return the regular practice of prescribed and cultural fire. Threats to the expanded application of fire include rising temperatures, narrowing burn windows, rapid human population growth and urbanization of the region, a growing wildland-urban-interface, and smoke management policies that constrain its use (Costanza et al. 2015; Kobziar et al. 2015). Further changes in regional prescribed burn windows linked to changing climate, air quality regulation, and a more urbanized workforce will further reduce application of prescribed and cultural fire (Kobziar et al. 2015) but increase the incidence and severity of large, escaped wildfires.

CENTRAL HARDWOODS AND APPALACHIAN MOUNTAINS

Lead Authors: R.M. Scheller, M.C. Stambaugh, and J.M. Varner

Similar to other areas of the eastern US, Indigenous populations were widely reduced by disease and displacement early in Euro-American colonization. Today, the only areas where more than 2% of the Indigenous population remains are in small enclaves along the southern edge of the Appalachians. Because Indigenous Peoples were displaced so long ago, less is known about regional cultural stewardship practices compared to areas with larger numbers of extant tribes such as in the northern Midwest and western US.

Historically, Indigenous burning practices were integral to land stewardship, and intentional burning was widespread (Fowler & Konopik 2007; Williams 1992). Fire scar studies and documentary records suggest that Indigenous stewardship was broadly similar to practices in neighboring provinces, although there was wide variation depending on dominant vegetation, topography, climate, and trade networks (Guyette et al. 2002; Hutchinson et al. 2019; Lafon et al. 2017; Stambaugh et al. 2020).

Lightning-ignited fires were relatively rare based on the historical characteristics of fire seasonality (largely occurring during the dormant season) and fire frequency (regular occurrence and relatively high frequency, Olson 1996). Other disturbances interacted with cultural burning such as livestock grazing and wild ungulate browsing, extreme weather events, insect outbreaks, and other biotic and abiotic disturbances (McEwan et al. 2011). Tornadoes and derechos (widespread and long duration windstorms deriving from intense thunderstorm activity) were relatively rare, but they episodically caused high canopy mortality within forested areas. Intentional burning was initially continued and even intensified by early European colonists to provide livestock forage and maintain open forest structure or prairie conditions for agriculture and livestock grazing (Flatley et al. 2013; Stambaugh et al. 2018). Flat landscapes – both at low elevations and on broad ridgetops and plateaus – were preferred areas to convert to small-scale agriculture through forest clearing (e.g., Whitney & DeCant 2003).

MAJOR ECOCULTURAL SYSTEMS

The region contains a diversity of ecocultural landscapes, spanning oak-hickory, oak-pine, pure eastern deciduous forests, woodlands, and high elevation conifer forests of the Appalachian Mountains. The Appalachian Mountains support the highest biodiversity of this region due to their rugged topography and history as glacial refugia during past ice ages in nearby provinces (Davis 1983; Delcourt & Delcourt 1981). Available evidence indicates that cultural burning was widely practiced at lower elevations with mean fire return intervals < 25 years, supporting forests dominated by black oak, red oak, scarlet oak, white oak, and chestnut oak, hickory, and American chestnut that supplied abundant plant foods and wildlife (Colenbaugh & Hagan 2023; Van Lear & Waldrop 1989). These fires frequently burned into higher elevations where dry ridges and south-facing slopes were dominated by pitch pine, shortleaf pine, Table Mountain pine, and occasionally eastern white pine. At high elevations, cultural burning is thought to be the original source of 'balds' – open grass and heath-dominated high-elevation meadows that attract wildlife in the summer months (Lindsay & Bratton 1979). East of this region, the New Jersey Pine Barrens are characterized by sandy soils and frequent fire (Scheller et al. 2011). Little is known of historical cultural burning practices within the Pine Barrens due to extensive colonial logging to supply firewood for nearby urban areas. However, pitch pine, the dominant species in the Barrens, along with shortleaf, loblolly, and pond pine are fire-adapted and fire-maintained species, signaling that frequent fire was a part of their development history over large areas.

To the north and west of the Appalachians is a broad area generally known as the Central Hardwoods (Figure 9). The Central Hardwoods are broadly characterized by the dominance (79%) of oak-hickory forests (Knapp et al. 2021), and elm-ash-cottonwood and oak-pine forests (Brandt et al. 2014; Hicks 1998). The region also contains pockets of more mesic hardwood and pine forests characteristic of the Great Lakes region, bottomland forest communities, and unique communities that developed on the karst topographies, where limestone, dolomite, and gypsum are the primary lithologies of the region (Baskin et al. 1997; Brandt et al. 2014; Hicks 1998). Similar to the Appalachians, available evidence indicates that cultural burning was widespread and maintained the forest types that dominate the area today. Central Hardwood forests today are dominated by mature second-growth

Figure 9. An open-canopy mixed hardwood forest in the Central Hardwoods region. Photo credit Michael Stambaugh.

forests and old-growth conditions are rare (Figure 10, Fraser et al. 2023).

DEPARTURES IN LANDSCAPE STRUCTURE, FUNCTION, AND COMPOSITION

With the notable exception of the high-elevation Appalachian mountain and ridgetops, agricultural clearing was widespread following European colonization. Staggered across the region, a successive pattern of land use change and development occurred as forts and towns were established and large-scale land clearing made way for agriculture and urban development (Hicks 1997; Spetich et al. 2011). Railroads resulted in widespread and destructive logging practices, particularly on steep slopes that were previously inaccessible to commercial operations. Some tree species, such as shortleaf pine, a fire-adapted species, were so heavily clearcut that seed sources were subsequently absent and this species failed to re-establish across much of its native range (Oswalt et al. 2012). Mirroring trends that began in New England and the southeastern US, fire suppression, the end of open range grazing, and later agricultural abandonment have resulted in widespread reforestation of abandoned fields during the 20th century (Kalisz 1986).

Over the last century, new and ongoing threats to forest health have overwritten the effects of the early land use changes. For example, the loss of the canopy dominant American chestnut to introduced chestnut blight strongly altered ecosystem structure, composition, and function (Boyd et al. 2013) and resulted in a tremendous loss of cultural values. More recently, ash have been radically reduced by the emerald ash borer; eastern hemlock has been decimated by the hemlock woolly adelgid, and American beech is threatened by beech leaf and beech bark diseases (Potter et al. 2019). Although these forests are often characterized by high biodiversity and contribute functional redundancy, many tree species occupy unique and culturally important niches and their loss reduces wildlife forage (e.g., chestnuts), impacts other important ecosystem services (e.g., carbon storage), and damages deep cultural relationships between humans and ecosystems. The introduction of non-native plants and animals has also altered ecosystems (Holmes et al. 2021; Kuhman et al. 2011). Fire exclusion has been another significant driver of forest change in the region over the past century (Abrams 1992; Nowacki & Abrams 2008). Fire exclusion originated with the cessation of cultural burning as practiced by Indigenous Peoples, and continued through the fragmentation of forests by roads, settlements, and active fire suppression. The subsequent reduction of fire frequency has resulted in vast regions of densified woodlands and widespread transitions to closed-canopy forests (Flatley et al. 2013, 2023; Oak et al. 2016).

While forest in-filling continues, shade-tolerant and fire sensitive 'mesophytic' species such as red maple and sugar maple, tulip poplar, black gum, and others have increased in abundance (Elliott & Vose 2011; Nowacki & Abrams 2008). The leaf litter of these mesophytic species has lower flammability than most oak or pine litter and impedes fire spread, leading to feedbacks that further resist ignition and burning. Additionally, mesophytic species often provide lower quality forage for wildlife and have a lower economic value in comparison with the oak and hickory dominated forest that they displaced. The rate and scale of the decline in oak regeneration is of particular concern because oaks are foundational to the region's ecology and economy (Vose & Elliott 2016; Colenbaugh & Hagan 2023).

The combined result of these departures is a regional transformation of forests that support some of the biodiversity prior to colonization but are under increasingly complex threats. Mature forests with complex structure are widespread in the region and are a cornerstone of many local economies. Due to the extensive alterations to forest composition, fire regimes, and land use changes that have occurred over this region, refugial old forests representing late-successional conditions exist today where topography or edaphic conditions have limited human influence and where the native species assemblages persist.

Figure 10. A mature mixed hardwood forest in the Central Hardwoods region. Photo credit Michael Stambaugh.

CONTEMPORARY AND EMERGING THREATS

Compounding threats will likely put forests of the region at further risk. Fire exclusion and conversion to mesophytic forest conditions remain significant and ongoing concerns. The loss of fire, which was historically supported through frequent cultural burning, threatens understory biodiversity, habitat for open-forest vertebrates and invertebrates, and timber resource values (Alexander et al. 2021; Nowacki & Abrams 2008). Globalization continues to introduce non-native insects and diseases that threaten biodiversity and forest health, and new tree diseases continually emerge (Lovett et al. 2016). The WUI is growing rapidly across the region as development continues (Hubert et al. 2023; Radeloff et al. 2005). The expanding WUI is responsible for the introduction of non-native plant and animal species (Bar-Massada et al. 2014) and the proliferation of some species, such as over-abundant white-tailed deer populations that browse in urban landscaping. Land development also fragments remaining forests, further constraining travel corridors and habitats.

Climate change multiplies many contemporary and emerging threats and will increasingly impact regional forest health. Although the average temperature and precipitation trends in Central Hardwood and Appalachian forests are not as pronounced as in the northern and western US, climatic variation has substantially increased and this trend will continue (Brandt et al. 2014). Climate change is expected to produce more episodic drought and extreme heat events, which could lead to tree regeneration failure and extensive tree mortality (e.g., Lawal et al. *in press*). More frequent and severe droughts will also exacerbate severe wildfire risk (Reilly et al. 2022). These circumstances will become more frequent in the coming decades, causing a potential five-fold increase in the incidence of wildfires across the southern Appalachians (Robbins et al. 2024). Given the expanding human populations in the WUI, an increase in the number of fire-vulnerable communities is expected. Additionally, extreme rainfall events are increasing (Du et al. 2019), which may cause human mortality and destruction of infrastructure.

The widespread loss of IK and Indigenous stewardship across the region is perhaps one of the gravest threats. Historically, Indigenous Peoples were active stewards of these landscapes and had generations of experience adapting communities and landscapes to change. Their stewardship created many of the remaining legacy old forests and woodlands of today.

GREAT LAKES AND NEW ENGLAND

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Figure 11. A red pine-dominated forest in north-central Minnesota at the University of Minnesota Cloquet Forestry Center. This forest was managed with fire by Indigenous Peoples for many generations and has been recently burned to restore vital ecocultural processes. Photo credit Kurt Kipfmueller.

Prior to European contact the area was home to culturally diverse Indigenous groups. All Indigenous groups experienced enormous changes to their landscape and culture ranging from complete erasure and cultural genocide to severe restrictions on their lifeways, cultural practices, land tenure, and stewardship. In much of the Great Lakes, seasonal movements of Indigenous Peoples tracked the availability of resources with winter hunting and spring maple sugar production supporting smaller groups. Summer and fall fishing and agricultural production attracted larger family groups to villages along lakeshores and major rivers. Large summer villages were also present across the Great Lakes and New England region. Summer agricultural production and berrying was a critical means of providing food surpluses to last the cold winter months. Nearly all Indigenous groups practiced some form of agricultural activity within the region, but the scale and reliance on warm-season crops varied locally and regionally and fire was widely used to clear and maintain agricultural landscapes and foraging areas.

Indigenous Peoples stewarded the ecosystems of the Great Lakes and New England through various land use activities, including agricultural development, preferential selection of specific resources, cultivation of orchards, and the use of fire (Figure 11). The role of Indigenous burning, particularly in New England, is a continuing subject of debate (e.g., Abrams & Nowacki 2020; Kellet et al. 2023; Oswald et al. 2020a, b). However, as IK is increasingly applied across the region, the large magnitude and broad extent of Indigenous culture has become more evident. While the ubiquity of Indigenous cultures may have been previously underestimated, new understanding of the importance of direct Indigenous stewardship in pre-Colonial forest development are increasing through the valuable contributions of traditional ecological and cultural knowledge systems (Smithwick et al. 2019). A growing body of evidence, including oral histories, dendroecological, and paleo reconstructions, has provided clear evidence of the importance of cultural fire use in pine-dominated forests and many other landscapes within the region. Fire proved to be a useful and efficient means to maintain plant and agricultural resources, clear portage routes, facilitate hunting, reduce pests, and reduce brush cover. Fires were also likely used elsewhere to support agricultural production and to maintain more open landscapes.

MAJOR ECOCULTURAL SYSTEMS

The North Woods region, including the Great Lakes and New England, span a broad transitional zone between the central hardwoods to the south and the boreal forests to the north (Pastor 2016). Although there is wide variation in vegetation within the region, most of the dominant tree species can be found throughout, except for a few that had not fully rebounded to their potential ranges following glacial retreat, or those more characteristic of southern latitudes found along the southern margins of the region. Forest composition varies latitudinally, merging from hardwood-dominated forest landscapes in the south to conifer-dominated forests in the north, with a wide zone of intermixing in between. Topographic differences and proximity to large water bodies have a strong influence on species composition that disrupts a smooth

Old-growth Northern Hardwood Forest
Western Lake Superior

Figure 12. Example of an old-growth northern hardwood forest. Illustration by Bob Van Pelt.

gradient in species change. In combination, the result is a diversity of ecosystems, including many unique assemblages such as pitch pine and jack pine barrens, cedar swamps, tamarack bogs, and others.

Although the unique species assemblages vary across the region, they maintain their general structural characteristics with respect to broad vegetation classifications (Figure 12). Northern, central, and southern hardwood communities are found throughout the region, with the more northern portions represented by mixed forests dominated by conifers. The transitions between these forest types are reflective of the east-west moisture gradient and strong north-south temperature contrasts. In the more southerly areas of the region, forest communities are dominated by oak-hickory forests that give way to beech-maple-basswood forests moving north. Extensive forests of trembling and bigtooth aspen are also prominent forest communities in more northerly areas, particularly post-19th century logging. Traversing north through the region, hardwoods yield to forests that include a greater coniferous component that, prior to widespread logging, were dominated by red pine, white pine, jack pine, and eastern hemlock, with localized deviations influenced by the presence of the Great Lakes. Extensive wetland areas add to the overall biodiversity of the region and include forested wetlands and peatlands supporting spruce, white-cedar, tamarack, cottonwood, ash, and maple.

Fire played a prominent role in the development of the structure and composition of the region as it existed at the time of European contact (Frelich et al. 2021). Historically, frequent fires maintained relatively open savannas from the western boundary along the Great Plains and southern region to the Atlantic Ocean, and northward to the near boreal mixed conifer and maple-hemlock forests. In the more northerly pine forests of the region, more frequent, non-lethal fires often occur at intervals less than 20 years. Surface fires were especially important in red and white pine-dominated forests that have declined following logging and due to aggressive fire and cultural suppression following Euro-American colonization. The biogeographic complexity of this region can in part be attributed to a broad range in fire regimes across the region with more frequent fires of mixed severity in pine-dominated forests yielding to relatively less frequent fire occurrence in hardwood-dominated stands and savanna ecosystems in the central and southern portions of the region. Fire played a prominent role in the development of the structure and composition of the more western Great Lakes area of the landscape as it existed at the time of European contact. The combination of climatic patterns and lightning ignition rates limits the number of lightning-caused fires across the region (Balch et al. 2017). The rate of dry lightning was low relative to other regions, and humans, past and present, were the primary agent of ignition. Prior to Euro-American colonization, drought-driven fires burned relatively large areas, sometimes as stand-replacement events, at 50-100 year intervals (Heinselman 1973). These lightning-driven fires augmented an historical anthropogenic fire regime that was largely dominated, at least in number, by relatively small patchy fires of relatively lower severity possibly dominated by cultural fire use (e.g., Booth et al. 2023; Kipfmueller et al. 2021; Loope & Anderton 1998; Muzika et al. 2015; Stambaugh et al. 2013). Surface fires were especially important in maintaining red and white pine-dominated forests (Ahlgren 1976).

In addition to fire, several other key disturbances shaped the forests of this region. Severe winds have had a major influence on forest ecological processes. Regional-scale straight line wind events associated with summer-time thunderstorm complexes can cause widespread forest mortality. For example, a straight line wind event on July 4, 1999, damaged almost 200,000 ha of forest in the Superior National Forest, with damage from the event extending from North Dakota northeast through Minnesota, Ontario, and Quebec. Smaller-scale events contribute to patch diversity by creating forest openings and increasing overall forest diversity (Lorimer & White 2003). Particularly in the northwestern area of this region, native insect outbreaks are also important to forest dynamics and include spruce budworm (Royama 1984) and jack-pine budworm (Kulman et al. 1963).

DEPARTURES IN LANDSCAPE STRUCTURE, FUNCTION, AND COMPOSITION

Euro-American colonization led to tremendous changes as the colonizers invaded lands traditionally used and stewarded by multiple Indigenous groups. While subsistence agriculture and the fur trade initially attracted European colonizers, these local effects were replaced by broader-scale, commercial activities including logging, mining, and market-oriented agriculture (Cronon 1992) that decimated regional forests. Logging of the vast pineries of the northern areas of the region led to a cascade of impacts, not least of which was the wholesale conversion of vast areas to stump fields that eventually succeeded to agricultural landscapes or type conversion to hardwood forests (Paulson et al. 2016). Following logging, aspen forests became dominant across many northern conifer areas, but other hardwood species also increased in areas formerly dominated by coniferous forest. Logging activities severely damaged upland habitats but also degraded lowland, riparian corridors, and waterways due to damage from log drives, siltation, and logging debris. The forced relocation of Indigenous Peoples to reservations resulted in the criminalization and elimination of reciprocal cultural practices, such as cultural burning, which sustained these forests.

In the eastern New England part of the region (not including Maine), intensive agriculture peaked around 1850, followed by forest recovery over the ensuing decades (Foster et al. 1998). Although these forests proved to be remarkably resilient, broadly speaking, they did not return to their pre-Euro-American colonization structure and composition. Post-agriculture forests are more homogenous than pre-colonial forests–in age and species composition –and, critically, Indigenous ecocultural practices are mostly absent. Although these are the most mesic of the region's forests, cultural burning was nonetheless widespread and important (Abrams and Nowacki 2020).

In the western Great Lakes half of the region, and across much of Maine, widespread logging activities, coupled with the conversion of landscapes for agriculture beginning in the early 1800s and extending through the century, led to dramatic shifts in vegetation patterns throughout the region. These extractive industries left little mature or old forests save a few postage-stamp remnant pockets widely scattered across the region (Dunwiddie et al. 1996; Frelich & Reich 1996).

Logging, followed by aggressive fire and cultural suppression, led to substantial changes in remnant and recovering forest communities (Paulson 2016). In general, the once extensive pine-dominated landscapes of the north converted to mixedwood forests, with a greater representation of hardwood species such as aspen, oaks, and maples. In general, the region has become much more homogeneous with the loss of unique and fine-scaled assemblages (Schulte et al. 2007). In more southerly areas of the region, the deviation in forest structure and composition has been marked by the loss of oak savannas due to agricultural clearance and fire exclusion (Grossman and Mladenoff 2007), leaving only fragmented remnants of savanna and prairie (Leach & Givnish 1996). Similarly, many extensive pine barrens, e.g., the Wisconsin pine barrens (Li & Waller 2015) and the New Jersey pine barrens (Scheller et al. 2008), were severely reduced and gradually converted toward structural patterns more closely resembling closed forests due to development and fire exclusion. The combination of reduced fire, coupled with increases in shade-tolerant hardwoods post-logging, has led to a mesophication of an increasing area of the region's forests (Figure 13, Nowacki & Abrams 2008).

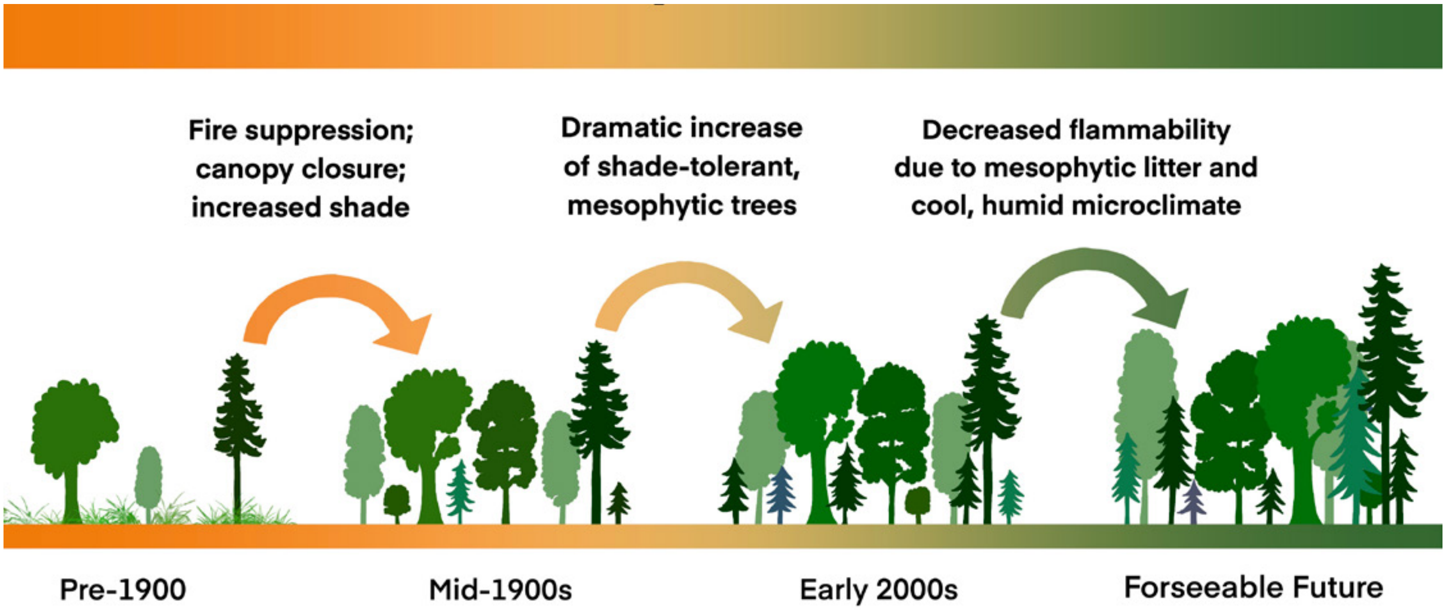

Figure 13. Conceptual diagram of mesophication over time in oak-pine ecosystems of the eastern United States. Figure adapted from Nowacki and Abrams 2008 by Jessie Thoreson.

CONTEMPORARY AND EMERGING THREATS

The list of contemporary and emerging threats in the Great Lakes and New England is long. Invasive species (e.g., insects and diseases), continued conversion to agriculture or urban development and resulting fragmentation, fire exclusion, climate change, overabundant herbivores, and extirpation of vertebrates and invertebrates all play major roles in past, contemporary, and future ecosystems in the region (Frelich & Reich 2009).

The importance of the Great Lakes and New England as major North American shipping and transportation systems has long facilitated the transfer of material goods and supported the fur trade early in colonial history (McDonnell 2015), with many travel routes developed and maintained by Indigenous Peoples (Nelson 2019). Infrastructure such as the locks and canals, connected commercial shipping between the Atlantic Ocean and the Great Lakes, opening the region to the introduction of novel species that in some cases have dramatically modified ecosystem structure, composition, and function. Although the role of novel aquatic species often garners the greatest attention (particularly in the Great Lakes portion of the region), introduced tree diseases and insects have affected these ecosystems for more than a century, with recent invasions having acute effects on the region's composition, structure, and dynamics. Notable diseases affecting canopy dominants include chestnut blight, Dutch elm disease, and beech bark diseases (Potter et al. 2019). Major introduced insects include spongy moth, Asian long-horned beetle, emerald ash borer, and hemlock wooly adelgid (Potter et al. 2019). The elimination of fire has led to more homogenous forest structure and composition, promoting broad-scale insect outbreaks.

An overarching threat to these forests is climate change. Increasing annual temperature and precipitation, coupled with an increase in the likelihood of heavy precipitation events are likely across the region (USGCRP 2023). Changes to precipitation regimes include more frequent transitions between wet-dry extremes, or a precipitation system that has greater interannual and multi-year variability, leading to the potential for more extreme fire years. Projections of marked increases in future fire activity (Gao et al. 2021) due to warming and drying suggest further widespread change in these ecosystems.

Shifts in climate are having dramatic and cascading effects on both biotic and abiotic environments. Although projected changes in the magnitude and severity of changes in temperature and precipitation patterns vary regionally, some broad trends and impacts are likely. Anthropogenic climate change will have dramatic and long-lasting impacts on the region's forest resources. Climate change will modify the rates and severity of severe storms including tornadoes, straight-line winds, and heavy precipitation events (USGCRP 2023). Shifting climate patterns will lead to modifications of climatic tolerance windows, shift phenological patterns in an array of forest communities, and may initiate changes to species ranges. Climate change has and will continue to cause shifting species ranges including the contraction of some ranges and expansion of others (Woodall et al. 2013), although substantial lags will slow this process (Davis 1989; Zhu et al. 2012). A warming climate will shift the climate envelope for many plant and animal species northward, and the encroachment of hardwoods into coniferous forests (Tang and Beckage 2010). Along with more than a century of fire suppression, and continued reductions in fire activity region-wide, hardwood species will continue to colonize formerly fire-dependent communities and alter forest structure and fire environments (Scheller et al. 2008). Culturally and economically important maple sugar production in northeastern and Great Lakes forests is also expected to decline across the region due to changes in growing season climate patterns driven by anthropogenic warming (e.g., Rapp et al. 2019).

Illustration by Bob Van Pelt

WESTERN TEMPERATE FORESTS

GEOGRAPHY AND CLIMATE

Temperate forests of western North America are comprised of a broad diversity of vegetation conditions oriented along steep climatic and topographic gradients. Forest types range from interior western montane mixed-conifer and mixedwood forests of the Cascade, Rocky Mountain, Sierra Nevada, and Klamath mountain ranges, pine and oak forests and woodlands of lower montane California, the southwestern US, and Mexico, and Pacific coastal forests of the western Cascades and Coastal Mountain Ranges. Shaped by seasonally dry Mediterranean to continental climates, most western forests are prone to wildfires, often beginning in mid-summer and extending into fall in some years. In the early 21st century, California now often experiences a year-round fire season.

The interior western montane forest region is dominated by dry and moist mixed-conifer forests at low and mid-elevations and cold subalpine forests and alpine meadows and heathlands at higher elevations. Across this diverse region, forests are strongly influenced by often steep temperature and precipitation gradients, winter snowpack, and pronounced growing season droughts. Annual fire frequency varies with climate and weather, and geographically with forest type and physiography. These dynamic landscapes reside within distinct subregions including the eastern Cascade Mountains of Oregon, Washington, and northern California, the Modoc Plateau of eastern Oregon and northern California, the Klamath and Siskiyou Mountains of southern Oregon and northern California, the Sierra Nevada of California, the Blue Mountains of eastern Oregon and western Idaho, the central Idaho Batholith, the Rocky Mountains stretching from northern New Mexico to southern British Columbia, the 'sky island' mountains of the Great Basin in Nevada and Utah, and the Okanogan Highlands of northern Washington and southern British Columbia (Figure 14).

The southwestern region of the US and that of northwestern Mexico support a diversity of forests within exceptionally varied terrain and biophysical environments. The regions span a wide range of elevations, from near sea level in the California Mediterranean province to mid-elevation forests in the Sierra Nevada, the Sky Island bioregion in the

Figure 14. Extent and major forest zones of the Western Temperate region.

southwestern US and northwestern Mexico, and the Gila Mountains of southwestern New Mexico. Precipitation is highly variable and seasonal. Winter precipitation across the region originates primarily from maritime polar moisture over the Pacific Ocean and is thus highly dependent on the El Niño-Southern Oscillation and Pacific Decadal Oscillation, extending into southeastern Arizona but only weakly farther east. Summer precipitation is largely driven by the North American Monsoon, which originates with maritime tropical moisture from the Gulf of California and Pacific. Monsoonal rainfall is strongest in the Sierra Nevada. Consequently, the California Mediterranean region receives winter precipitation followed by an almost completely rain-free summer with the exception of periodic summer monsoonal rainfall, whereas ecosystems of southern New Mexico receive most of their annual rainfall from the summer monsoon. The Sky Islands and Sierra Madre Occidental are uniquely positioned for a bimodal rainfall pattern, with both Pacific and Monsoon storms bringing precipitation. Forests of the region are adapted to these seasonal rainfall patterns, with annual dormancy driven by the driest periods of the year.

The Pacific Coast Region spans nearly 25 degrees of latitude adjacent to the Pacific Ocean, from California to southcentral Alaska, extending east to include nearby coastal mountain ranges and the west slope of the Cascade Mountain Range. Climatically, this coastal region is generally characterized by generally mild temperatures and abundant winter precipitation, varying substantially across north-south latitudinal and east-west topographic gradients. South of the Canadian border, moisture is greatest near the coast and declines eastward toward the Cascade Range crest. Warm, dry periods that support fire reliably occur from June to October, especially in the central and southern Cascade Range, Siskiyou Range, and the drier Willamette Valley and Puget lowlands east, west, and north of the Puget Sound. Along the coast, summer maritime fog provides continued moisture to coastal redwood, Sitka spruce, and moist mixed-conifer forests. North of the Canadian border, a perhumid (wet year-round) climate dominates, and extended periods of moisture limitation are infrequent. Temperatures are cool, but extreme lows are relatively rare due to a strong maritime climatic influence, however, this is changing with climate driven changes in the tracking of the circumpolar jet stream. The distribution of major ecocultural systems aligns closely with this broad geographic variation in climate.

CLIMATE AND WILDFIRE ADAPTATION STRATEGIES

MIXED CONIFER FORESTS

Forested landscapes of this region face increasing and often synergistic threats from wildfires, drought, insects, agriculture and urban development, and climate change. All forests within this seasonally dry and fire-prone region dynamically evolve over time. Dynamism is expressed within provincial-scale lifeform patterns of vegetation, within intermediate-scale, local landscape patterns of forest and nonforest vegetation, with their open and closed canopy conditions and varied age classes, and within the finer patch-scale variation of clumped and gapped tree conditions.

Long-term stewardship practices are most successful if they aim to restore climate-adapted wildfire regimes and the forest and nonforest (Figure 15) successional and fuel conditions that will most likely support them. Emphasizing the quantity of any one particular condition over these supportive conditions changes the dynamics, often in counterproductive ways.

Figure 15. Ponderosa pine woodlands and shrub steppe present in eastern Washington.

In this light, old forests are an emergent property of these supportive pattern and process linkages. Fire, both natural and human ignited, is a fundamental process across nearly all ecocultural systems of this region (Falk et al. 2011; Perry et al. 2011; Hessburg et al. 2019). Ecocultural restoration strategies are centered on restoring the active role of people and fire to forests. The role of fire though, differs substantially across the diverse landscapes of the region and is further nuanced based on historical Indigenous uses of fire. Hence, we promote restoration of beneficial fire while encouraging that place-based knowledge sources are actively integrated to inform stewardship practices (Lake et al. 2017; Wynecoop et al. 2019; Long et al. 2021).

Many forests of the region are uncharacteristically dense and layered compared to historical conditions. With such highly departed structure and composition, reintroducing fire on its own presents a grave challenge. In many places, before fire can be realistically reintroduced, silvicultural treatments are needed to restore forests that can survive fire. These more receptive conditions can increase the likelihood of meeting fire behavior and fire effects objectives. By using a range of ecocultural restoration strategies (Table 3), we can strategically guide the return of fire into fire excluded landscapes to benefit humans and ecosystems, while promoting the long-term durability of the old and mature forests.

Large fires and insect disturbances will continue to impact these landscapes before many ecocultural restoration treatments can be implemented. Where disturbances interact with highly departed landscapes, active, post-disturbance stewardship will be critical. Applied effectively, and in response to detailed post-disturbance evaluations (Larson et al. 2022; Churchill et al. 2022), treatments such as forest thinning, tree planting, and proactive burning can be used to ensure that landscapes will be more receptive to subsequent fires, other disturbances, and climate change, while mitigating widespread loss of old and mature forests.

Post-disturbance treatments also provide a key opportunity to practice adaptive stewardship. Applying

Table 3. Adaptation toolbox for temperate western North American forests. Continued on next page.

Adaptation strategy	Description	Ecocultural system(s)	Threat(s) addressed
Cultural burning – patch scale	Place-based burning with place-based values instrumental in guiding burn plans and related prescriptions	All	Loss of cultural burning, fire exclusion, maladaptation to climate change, wildfires, insects and pathogens
Cultural burning – landscape scale	Place-based burning to restore larger landscape patterns, patch-scale cultural burning prescription are included (as above) as are burns plans and prescriptions that restore cultural resources over larger areas and landscape successional conditions that restore a climate adapted fire regime.	All	Loss of cultural burning, fire exclusion, maladaptation to climate change, wildfires, insects and pathogens
Prescribed underburning	Fuel reduction treatment either alone or after forest thinning emulates native fire regime, favors open canopy conditions and thriving understory communities of native species	Pine/oak forests and woodlands, dry or moist mixed conifer forests as is appropriate	Loss of frequent fire and its fuel reducing effects, fire exclusion, maladaptation to climate change, wildfires, insects and pathogens
Prescribed crown fires	Prescribed crown fires to kill overstory trees, restores the nonforest patchwork and varied successional conditions, re-establishes fences to fire flow	Aspen forest, cold forest patchwork restoration	Loss of aspen and other hardwood forests, loss of landscape patterns of burned and recovering cold forest successional patches and meadows.
Dynamic conservation areas	Allows for proactive fire stewardship within mature and old forests that allows for restored cultural burning and other tending practices	Ponderosa pine forests and savannas, mixed conifer forests, Pacific maritime forests	Climate change and wildfire regime adaptation, adaptation to drought, insects and pathogens
Forest thinning	Reduce density of small diameter trees and shift to more fire and climate resilient species composition	Oak/pine forests and woodlands, dry/moist mixed conifer forests	Fire exclusion, maladaptation to climate change, wildfires, insects and pathogens
Meadow and shrubland enhancement and restoration	Group selection or patch cutting and/or prescribed burning to re-establish wet meadows in appropriate sub-irrigated terrains, dry meadows where they have been encroached, and shrublands that are often reburned.	All	Loss of nonforest communities, mitigation of future large and severe wildfires
Managed wildfires	Unplanned wildfires managed for fire use in the backcountry in cold and moist forests. Re-establish fences to fire flow and nonforest areas that can carry low intensity fires.	Cold and moist forests away from communities	Loss of resilient patch mosaics, loss of open canopy conditions familiar to moist and cold forests, mitigation of future large and severe wildfires

Table 3. Adaptation toolbox for temperate western North American forests. Continued from previous page.

Adaptation strategy	Description	Ecocultural system(s)	Threat(s) addressed
Post-fire transition to nonforest	Guide some areas burned in high severity back to meadows and shrublands where warmer and drier climate and climatic water deficit will poorly support tree regeneration and establishment and where restoration of openings is appropriate.	All (post-fire)	Loss of nonforest communities, mitigation of future large and severe wildfires
Post-fire tree planting	Strategic tree planting to assist in large, high severity patches that are either seed limited or seed sources are maladapted to climate change and future wildfires	All (post-fire)	Maladaptation to climate change
Post-fire fuel reduction	Post-fire thinning and prescribed burning to remove the fire excluded forest infilling that contributed to the severe fire and will severely reburn in the next fire, mitigate future fire severity and enhance resilient structure and composition.	All (post-fire)	Fire exclusion, maladaptation to climate change, wildfires, insects and pathogens

strategies that adapt landscapes to future climates involves accepting some uncertainty. New strategies can be compared with traditional approaches and learning can result (Higuera et al. 2019; McWethy et al. 2019).

Without strong monitoring systems that allow learning while doing, ecocultural restoration cannot be successful. Varied management trials, monitoring, and adjustments to practices are needed and are keystones of Indigenous stewardship. As adaptation strategies are applied, monitoring efforts then evaluate how ecological and social outcomes have been affected by treatments at relevant scales, and how current conditions align with contemporary or projected climates, disturbance regimes, and local cultural values (Wynecoop et al. 2019). Adaptive monitoring can then be used to design future treatments and prioritize stands and landscapes in decades that follow.

PINE AND OAK WOODLANDS AND FORESTS

Seasonally dry pine-oak forest and woodland systems often display some of the most departed fire regimes and forest or woodland conditions, and the effects of long absent cultural stewardship practices is often most notable. In many fire-suppressed areas, large conifers have overtaken older hardwood trees, and encroached prairies, and meadows. Consequently, restoration may require removal of large but young conifer trees and adoption of new standards to identify old or ancient oaks. Restoration and climate adaptation strategies may need to address a common bias in forest policy and management practice that favors conifers based upon commercial timber market value rather than broader ecocultural significance of hardwoods. In this light, postfire restoration strategies would need to consider opportunities to rely upon resprouting hardwoods and creating space for them to grow to meet reforestation and Indigenous cultural stewardship goals, especially in areas where long-standing practices of planting pines and other conifers will likely fail under climate change (Long et al. 2023). In contrast, some places may have conditions that allow return of fire without extensive pre-treatments (Pawlikowski et al. 2019). In other areas, a combination of treatment approaches may be desirable to sustain old hardwood growth and other values.

Restoring frequent fire regimes and reducing unnaturally high fuel loads both before and after wildfires are important strategies to promote resilience of older pine and oak dominated forests and sparsely treed woodlands, ensure growth of replacement trees, and sustain traditional gathering sites for future generations. For example, on the San Carlos Apache Reservation in Arizona, treatments have included thinning, prescribed burns and managed natural ignitions, even during the summer wildfire season, as part of an integrated effort to restore fire regimes, promote cultural resources, and conserve old growth pines and oaks (Victor 2014). Such approaches have been highlighted to address both drought and wildfire hazards associated with climate change (Stephens et al. 2018; Redmond et al. 2023; Sankey and Tatum 2022). Resuming forest stewardship practices, especially in oak and other hardwood groves, can promote resilience to fire and other disturbances. This may be accomplished by removing dead branches, duff, and very low branches that connect canopies to ground fuels, by regulating the supply of food for insect pests, and by reducing water stress. However, it is also important to note that returning intentional fire has sometimes been associated with mortality of mature trees; for example, reintroduction of prescribed fire at the Teakettle Experimental Forest in the Sierra National Forest, CA was associated with killing of large diameter pines due to the combination of fire damage and beetle invasion (Maloney et al. 2008).

Some Tribal and non-Tribal forest restoration practitioners have cautioned against treatments that differ from traditional stewardship[1] and assert that fire treatments can be carefully applied to avoid damage to old trees and other spiritually and culturally important values. Initial fires using strategically designed timing and placement of ignitions can decrease stand density while allowing subsequent maintenance burns to re-establish open canopy conditions over time. Mitigation measures can include physically pulling back some of the deep litter and duff layers from the boles of mature trees, tree-centered firing, and applying fire during periods when fire effects will be less severe (Long et al. 2018; Weatherspoon et al. 1989; Weatherspoon & Skinner 1995). After a long period of fire exclusion, duff and litter accumulations are often deep enough to support deep smoldering combustion over long enough periods that basal scorching, scalding, and mortality of even very old, thick-barked trees can result.

PACIFIC COASTAL FORESTS

Indigenous Knowledge of past stewardship approaches and the resulting landscape conditions can help inform contemporary approaches to stewarding Pacific Coast forests for diversity and resiliency in the face of climate change and other related stressors. Current approaches to enhancing and protecting old ecosystems in the Pacific Coast Region have used large block reserve designations to promote large contiguous areas of old forest cover (Spies et al. 2018, 2019). This approach is premised upon certain historical inaccuracies. The stages of forest development culminating in what we now consider and call *old* began with the forced removal of Indigenous Peoples and their stewardship of these forested geographies. In this way, *old* thought of in this light is yet another legacy of settler colonialism. Therefore, while old forests have evolved over the past 400-1200 years or more without human stewardship, it is inaccurate to assume that those lands were not stewarded by human hands prior to that time. Indigenous Knowledge tells us that these landscapes were historically stewarded to provide a patchy mosaic of old and young trees as well as nonforest conditions, where old forests and old trees were only a part of a more diverse landscape. Where zoned management designations have failed to provide for a diverse mosaic of forest and nonforest conditions, a more proactive stewardship approach can be used to steward the entire landscape in a way that better promotes diversity and resiliency. Such approaches can include selective harvest, the creation of openings, and the application of prescribed fire to create a diversity of forest conditions.

PLACE-BASED EXAMPLES

Yurok Territory in the Klamath Basin: Adaptive Stewardship where Ecoregions Converge

Paiute-Jeffrey Pine-Piagi System

Anderson Lake British Columbia

Managed Wildfire in Illilouette Creek Basin

1 Pile burning and mastication can often damage understories – the point of much cultural burning – and can make the understory of the affected area relatively depauperate in comparison with result from cultural burning practices. Pile burning consumes small and larger fuels rather than just the smaller kindling fuels, leaving less charcoal that can erode and enter into soils as biochar. Mastication reduces surface and ladder fuels into smaller sizes, which can decay faster, but that ties up nitrogen as they decay for quite long periods of time.

INTERIOR WESTERN MONTANE FORESTS

Lead authors: P. Hessburg, C. Chamberlain, G. Cova, C. Desautel, S. Prichard, and Z. Steel

The ecological diversity and culture of this region prior to Euro-American colonization provide a template for adaptive stewardship of these forests today. Indigenous fire stewardship influenced not only the structure and composition of major ecocultural systems, but also the overall resilience of these landscapes to fire, drought, and other agents of change (Kimmerer & Lake 2001; Klimaszewski-Patterson et al. 2018; Knight et al. 2022). With such wide variation in environments across interior western montane (IWM) forests, place-based stewardship eludes broad generalizations. However, cultural fire use is recognized as having a widespread influence on native fire regimes and forest landscapes throughout this diverse region.

Early western literature asserted that Indigenous burning influences were confined to relatively small portions of the landscape close to villages and trails. However, the influence of Indigenous fire stewardship over broad landscapes is well known by IK experts and has been increasingly documented through peer-reviewed research drawing upon a variety of methods.

Oral and written histories of Indigenous burning practices corroborate some of the complex seasonal patterns of burning that are documented in paleoecological records (Roos et al. 2021, 2022; Swetnam et al. 2016; Taylor et al. 2016). Moreover, fire scar records provide strong evidence of Indigenous influence, such as increased burning outside the period when lightning ignitions were most common (Valliant & Stephens 2009). Even so, fire scars offer a conservative estimate of fire frequency because not all frequent low-intensity fires are recorded as scars (Roos et al. 2022). Furthermore, pollen records and integrative modeling indicate frequent, low-intensity Indigenous burning created and maintained low density, open forests over large areas in the central and southern Sierra Nevada prior to Euro-American colonization (Klimaszewski-Patterson et al. 2018, 2024; Klimaszewski-Patterson & Mensing 2016). Across IWM forests, widespread cultural burning and other stewardship practices historically promoted multi-scaled ecological and community resilience.

MAJOR ECOCULTURAL SYSTEMS

SEMI-ARID PINE AND MIXED CONIFER FORESTS AND WOODLANDS

Across the range of ponderosa and Jeffrey pine, fire scar records reveal that both pine and dry mixed-conifer forests supported frequent fires, with mean fire return intervals ranging from 5-25 years (see review by Hagmann et al. 2021). Ponderosa pine and Jeffrey pine have relatively long needles, high needle turnover, and a propensity for lower branch pruning, which supports an ongoing flammable litter layer under trees. Moreover, with a foliage and branch geometry that dissipates rather than traps heat energy from fires, low and moderate severity fires are typically supported by these species (Agee 1990, 1996). Frequent burning favors fire-resistant pine over shade-tolerant grand and white fir and Douglas-fir. Indigenous fire use was historically widespread across pine and dry mixed-conifer forests, where annual and semi-annual underburning often increased fire frequency and extended fire seasons into early spring and late fall. The combined work of cultural burning and lightning fires supported open woodlands and forests with low canopy cover and low potential for high severity fire (Stephens et al. 2015). These low-density forest and woodlands existed within dynamic landscape mosaics of grasslands and wet and dry meadows (Hessburg et al. 2019; Safford & Stevens 2017).

Prior to Euro-American colonization, cultural burning was widely used in pine and mixed-conifer forests to promote open canopy conditions that supported diverse understories of native grasses and herbs, providing foods and medicines for people as well as forage conditions for hunted animals. Under open canopies, fire-maintained understories supported thriving bunchgrasses, edible herbs (e.g., balsamroot sunflower and various geophytes known as Indian potatoes), berry- (e.g., serviceberry, huckleberry), and nut-producing shrubs (e.g., hazelnut) and small hardwood trees (Marks-Block et al. 2021). Intermixed patches of hardwood forests served as seasonal barriers to fire spread due to their high foliar moisture content during spring and summer growing seasons (Perry et al. 2011). Although many cultural burns were small patch burns for cultivating specific foods, medicines, and other culturally valued resources, broader landscape-scale burns have long been used to maintain open canopy grass-dominated habitat for important game species and berry fields for late summer and fall harvesting (Boyd 1999; Knight et al. 2022; Long et al. 2021).

Historically, frequent burning in pine and dry mixed-conifer forests contributed to the sustainability of old forests and trees, with ponderosa pine, western larch, Douglas-fir and other fire-resistant conifers commonly exceeding 300-400 years in age. While pine and mixed-conifer forest landscapes are more than capable of supporting large to very large fires (> 10,000 ha), prior to Euro-American colonization, Indigenous practices modulated fire regimes and limited area burned (Taylor et al. 2016). Most fires remained small- to medium-sized (< 1,000 ha), and when large fires occurred, they primarily burned the understories, while typically sparing many overstory trees (Haugo et al. 2019; Williams et al. 2023). High severity fires resulting in near-complete overstory mortality were indeed part of the historical fire regime, but high severity patch sizes were relatively small and limited by past fire events (Williams et al. 2023). Instead of creating landscapes where future fires would be destructive, cultural burning coupled with lightning fires promoted forests that were receptive to future fires and resilient to episodic drought, forest diseases, insect outbreaks, and variations in climate.

MIXED CONIFER AND HARDWOOD FORESTS ON MOIST SITES

IWM forests are often characterized by rugged, often deeply dissected topography, which in turn produces complex, topographically-driven forest types and species composition. Dry pine and mixed-conifer forests are found on more exposed southwestern slopes, while moist mixed-conifer forests are found on cooler, north- and east-facing slopes and in valley bottoms (Figure 16). Riparian forests, commonly composed of hardwood species like cottonwood, aspen, maples, alders, and birch, further dissect IWM landscapes. Many dry and moist forests, including riparian areas, share similar fire histories in the interior West, suggesting that frequent fires burning in upland pine and mixed-conifer forests were frequently delivered to moist mixed-conifer and riparian forests (Agee 1996; Everett et al. 2003; Harley et al. 2020; Wright & Agee 2004).

Moist mixed conifer forests are home to a variety of edible berries, which generally favor partial shading and moderate sunshine during the growing and ripening seasons (Anzinger 2002; Minore 1972; Shores et al. 2019). Such areas have been regularly burned and cultivated to maintain healthy shrub conditions with the right amount of overstory shading, and useful shrub heights for easier harvest. Cultural burning of riparian forests has long been conducted for a wide

Figure 16. Moist mixed conifer with aspen forest. Methow Valley, WA.

variety of reasons (Hankins 2006, 2013; Long et al. 2021). Often, small patches and individual plants have been burned to enhance production of willow, hazel, and other plants important for basketry materials and influence their physical and chemical properties (Marks-Block et al. 2021). Indigenous burning has also been used to favor shade intolerant trees such as aspen and cottonwood and understory grasses and forbs in mixed-conifer forests to enhance habitat for ungulates (Kay 2000).

COLD MIXED-CONIFER FORESTS

Across the broad geographic range of the IWM, cold mixed-conifer forests are found in high elevation environments, where long, cold winters, and deep snowpack occur. These forests are generally dominated by lodgepole pine, subalpine fir, Engelmann spruce, and quaking aspen, which can recruit and survive in harsh environments and with marked seasonal changes in precipitation, solar radiation, temperature, and weather extremes throughout the year. With relatively short growing seasons and short windows when fuels are potentially available to burn, cold forests generally display longer fire return intervals than dry and moist mixed conifer forests at lower elevations and/or latitudes.

Although fire return intervals could range from between 30 to 150 years at any one location, fire was common across cold forest landscapes, occurring somewhere across the broader landscape most years. Prior to Euro-American colonization and before the onset of fire exclusion, cold forest landscapes were characterized by burned and recovering patchworks of differently aged forests. Fires contributed to complex mosaics of subalpine and alpine meadows, young, middle-aged, and older forests, and open and closed

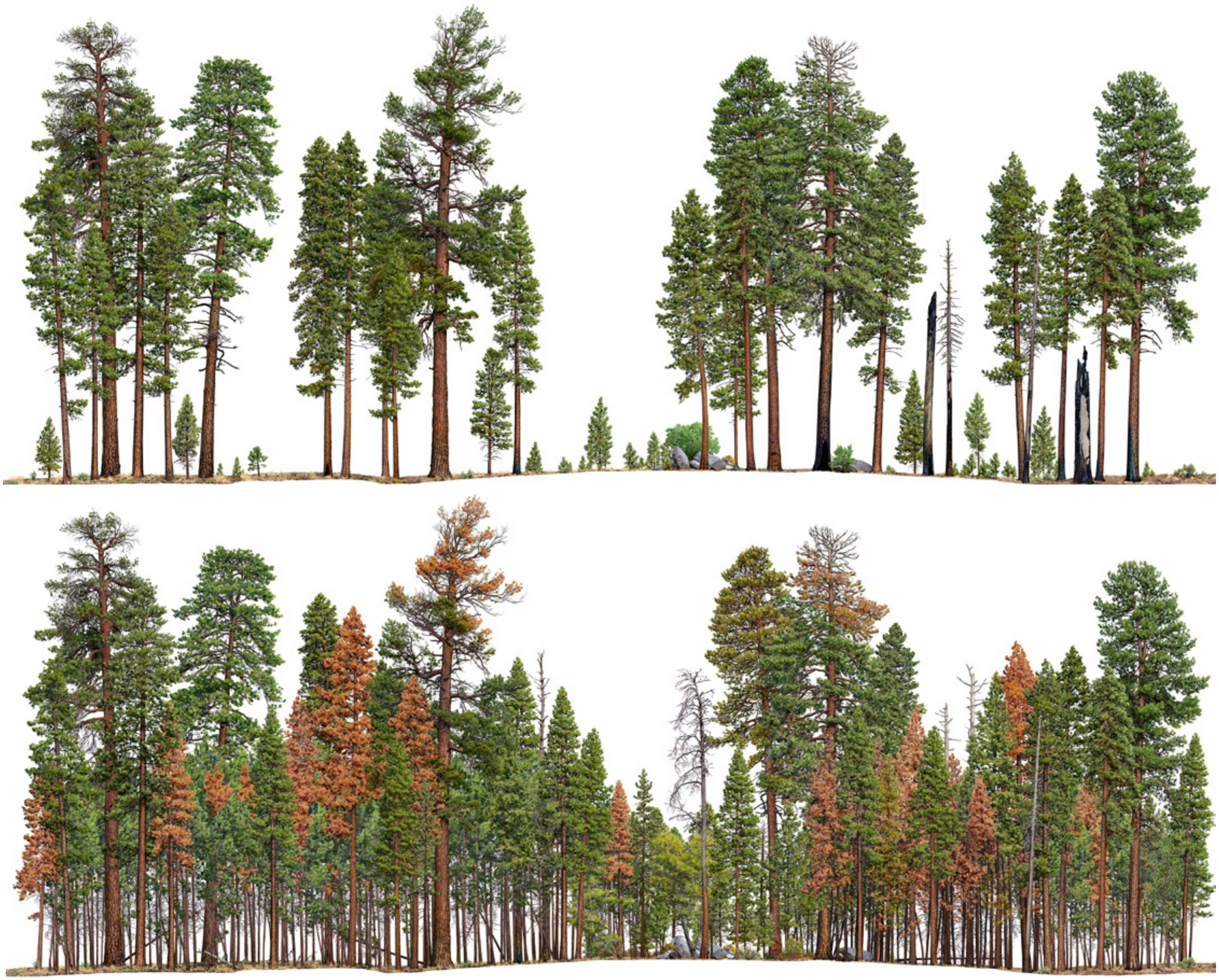

Figure 17. Difference in forest structure and condition between a fire-maintained (top) and fire-excluded (bottom) ponderosa pine forest after 80 years. Illustration by Bob Van Pelt.

canopy conditions (Povak et al. 2023). Under typical fire seasons, past burn mosaics limited the size and severity of fires; however, exceptionally dry years and unique configuration of patches with high crown fire potential could support large fire growth and high fire severity, where ignitions occurred (Povak et al. 2023).

Historically, Indigenous burning in cold forests was common and typically occurred in late summer and early fall when fuels were dry enough to support burning. These fires supported meadows and berry fields that are important for summer hunting and gathering (LeCompte-Mastenbrook 2015). Indigenous burning sustained aspen in many cold forests (Kay 2000), and high mountain tops and ridge systems were important for ceremonial purposes as well and used as travel ways between seasonal hunting and gathering sites and for trading among tribes, bands, or family groups (Turner et al. 2011).

CONTEMPORARY AND EMERGING THREATS

IWM forest landscapes and the mature and old forests contained within currently face numerous and often synergistic threats. In many places, anthropogenic climate change amplifies existing stressors and is pushing many forest landscapes toward tipping points beyond which forest recovery or restoration may not

Figure 18. Changes in forest structure between 1934 (left) and 2021 (right) along Buttermilk Butte near Twisp, WA. Photo credit Robert Cooper (left) and John Marshall (right).

be possible (Coop et al. 2020). Many of the current threats to IWM forest landscapes are extensions of factors that began during Euro-American colonization, including loss of Indigenous stewardship, ongoing fire suppression, continued harvest of old trees, and expanded development within the WUI.

Through active fire suppression, fire exclusion continues to change forest landscapes by accumulating hazardous fuels and increasing fire risk (Figure 17). Indeed, the "no action" or "business as usual" alternative within forest management planning poses one of the greatest ongoing and increasing threats to IWM landscapes (Hessburg et al. 2021; Prichard et al. 2021). In the continued absence of fire, shade-tolerant and fire-sensitive trees gain greater dominance at the loss of fire-dependent tree species, and fuels accumulate in forest understories, predisposing them to high-severity wildfires with cascading impacts to wildlife habitat, watersheds, carbon stores and human communities (Knapp et al. 2013; Merschel et al. 2021; North et al. 2015). To date, active fire suppression in the US successfully extinguishes 97-98% of active ignitions. However, the 2-3% of fires that escape suppression (Calkin et al. 2015) are typically those that burn during extreme fire weather events, and consequently account for a vast majority of the annual area burned (Coop et al. 2022). Uncharacteristically large "mega-fires" are often composed of large (> 1000 ha) high-severity patches (Cova et al. 2023), which prohibit or delay natural regeneration of many tree species that require a living seed source (Coop et al. 2020; Steel et al. 2018; Stevens et al. 2017; Welch et al. 2016).

Direct human impacts on old forests, such as timber harvest, land clearing, and expansion of the WUI, continue across the western United States yet vary greatly among land ownership and geographic regions. While logging of Pacific coastal old forests mostly ended on public lands with the establishment of the Northwest Forest Plan (Davis et al. 2015), intensive harvest of mature forests continues in some areas, particularly on private lands (McKinley et al. 2011; Soulard et al. 2017). However, in dry forests subject to recent increases in severe ecological disturbances, combined losses from wildfire, drought, and beetle attack currently outpace losses from timber harvest (Steel et al. 2021).

Development within the WUI has accelerated in recent years as new homes are built in proximity to forests and recreational opportunities (Carlson et al. 2022; Radeloff et al. 2018). In addition to the direct and permanent conversion of forests, WUI expansion also increases potential wildfire ignition sources (Balch et al. 2017), reduces the ability to intentionally burn under moderate weather conditions (i.e., prescribed or managed wildfire; Radeloff et al. 2018), and focuses fire suppression resources around homes and infrastructure rather than at fire's edge where they could be more effective.

Changes in forest structure and composition (Figure 18) – coupled with accelerating climate change – are leading to rapid shifts in disturbance regimes. Wildfires and drought are currently among the most significant agents of ecological change in IWM forests, with impacts expected to accelerate in the coming decades under climate change. Between 1985 and 2017 there was an eightfold increase in the area burned at high-severity in western forests (Parks & Abatzoglou 2020). Increases in burn severity can be attributed to a combination of changes in forest structure and density due to fire suppression (Steel et al. 2015) as well as warmer and drier conditions over longer periods associated with climate change (Parks & Abatzoglou 2020). The area burned by wildfires is projected to increase three-fold by 2050 under climate change (Abatzoglou et al. 2021).

Drought and associated beetle infestations are also major drivers of change in IWM forests. As with wildland fires, these agents of change have always been a part of dynamic landscapes (Covington & Moore 1994). However, climate change is extending and worsening otherwise typical drought conditions (McCauley et al. 2022), and dense, fire-excluded forests are highly susceptible to forest insects, particularly during periods of drought and longer-time changes in soil water deficits (Merschell et al. 2021). Shorter and warmer winters also provide more suitable conditions for insect populations such as bark beetles to expand and create large outbreaks. Cold mixed-conifer forests at higher elevations have also become increasingly homogenous in their age distributions and species compositions, placing these forests at higher risk to beetle outbreaks and widespread mortality of mature and old trees.

Combinations of insect outbreaks, pathogens, drought, and wildfires pose multiple and compounding threats to western forests. For example, where wildfires burn areas of recent beetle-caused mortality, burn severity can be elevated in some forest types including cold forests and dry mixed conifer forests (Talucci et al. 2022; Wayman & Safford 2021). Similarly, episodic drought contributes directly to tree mortality but also weakens trees and makes forests more vulnerable to insects and disease and severe wildfires (Sieg et al. 2017; Stephens et al. 2018).

Forest recovery following wildfire is also challenged by a changing climate. In particular, along the warmer and drier edges of forests, post-fire conditions may no longer be suitable for the forests to recover their pre-fire composition (Davis et al. 2019; Stevens-Rumann et al. 2018). Uncharacteristically large patches of fire-caused overstory mortality present major challenges for future tree regeneration under warmer, drier climates. In addition to limited seed availability, when the interiors of such patches are exposed to elevated temperatures and drier than historic soil moisture, re-establishment of trees can fail, potentially resulting in permanent type conversion to grasslands and shrublands (Coop et al. 2020; Stevens-Rumann & Morgan 2019).

In some forests, climate change is also associated with a marked increase in short-interval fires, with implications for mature and old forest recruitment and persistence. When dense forests burn in high-severity fire events, dead and downed wood accumulations predispose regenerating forests to high-severity reburn events (Coppoletta et al. 2016; Prichard et al. 2017; Steel et al. 2021). Short-interval reburns, particularly those that burn through young conifer forests before they produce seed, threaten the ability of slow-growing cold forests to recover (Coop et al. 2020; Higuera et al. 2021; Prichard et al. 2017; Turner et al. 2019).

Climate change is expected to cause uphill and northerly shifts in climate and environmental conditions. That is, the mid-montane climates that support ponderosa pine forests will soon be the climatic conditions that dominate the dry mixed-conifer zone at higher elevations, and so forth. Some novel plant and animal community assemblages are likely with these transitions (Meigs et al. 2023). Thus, because some existing ecosystems and plant and animal assemblages will not be adapted to future climatic conditions, topographic and latitudinal gradients may be used as planning templates to better align vegetation communities and disturbance regimes with future, downslope, climate conditions (Churchill et al. 2022; Meigs et al. 2023).

PINE AND OAK FORESTS AND WOODLANDS OF CALIFORNIA, SOUTHWESTERN US, AND MEXICO

Lead authors: J. Long, D. Falk, D. Hankins, and L. Quinn-Davidson

Landscape diversity—and the cultural context with which it evolved—is critical for understanding both reference conditions for ecological restoration in the region and the potential for adaptation under a changing climate. This diverse region contains some of the oldest ecocultural systems in North America (Swetnam & Brown 1992). The intermingling and interspersion of ecocultural systems and stewardship, often with fire, have supported both large and diverse human populations for millennia, making it one of the longest occupied areas on the continent. Even at the last glacial maximum, many areas were ice-free, with extensive woodlands and savannas in areas that today support desert grasslands and shrublands.

Across the region, Indigenous stewardship has enhanced the diversity and interaction of ecosystems and ecotones, such as wet coastal areas, hardwood-dominated woodlands, shrublands, conifer-dominated forests, wetlands, grasslands, and prairies to fulfill the needs of Indigenous communities and their relationship and obligations to place. Despite profound changes in these systems since Euro-American colonization, this ecocultural region retains a rich cultural and biological diversity, including hundreds of Native Nations and Indigenous languages, and iconic examples of old forest systems and old trees, including some of the largest, tallest, and oldest individual trees (Swetnam & Brown 1992).

Prior to Euro-American colonization, the Pacific coast, lowland areas along major river systems, and Pueblo communities supported dense Indigenous populations. The surrounding landscapes of California and the Southwest region included woodlands and savannas dominated by various assemblages of oaks and conifers including pinyon pines and junipers. Indigenous stewardship of these forests and woodlands supported wild and cultivated food production including summer farming at middle and upper elevations, especially in areas with summer monsoon rains (Roos et al. 2022). These forests were sometimes isolated on mountain ranges and interspersed with shifting woodlands and shrublands (Roos et al. 2021).

MAJOR ECOCULTURAL SYSTEMS

Both forests and Indigenous Peoples of the region evolved with and depend on fire. Indigenous stewardship practices have shaped and enhanced biodiversity through variable fire regimes rooted in cultural needs and indicators, working in tandem with frequent natural ignitions. Indigenous stewardship represents a complex relationship in each given place, but it commonly calls for relatively frequent fire to support diverse objectives (Anderson 2005; Hankins 2021; Lewis 1973). In this section, we focus on pine and hardwood-dominated forests characterized by frequent, low-severity fire regimes that were common across the region.

Pine and oak woodlands contain an outstanding diversity of habitats and high rates of endemism throughout California, the southwestern US, and northwestern Mexico. Within California alone, there are over 2,000 endemic species, including 3 pine and 8 oak species. Madrean oak-pine systems throughout the southwestern US and northwestern Mexico also contain high rates of endemism and are considered biodiversity hotspots of the world due to varied topography and climatic extremes. Important ecocultural systems include yellow pine (Jeffrey and ponderosa pine) dominated forests and savannas, oak woodlands of California, mixed evergreen forests, oak-pine woodlands and forests, and pinyon pine and juniper woodlands.

Throughout this region, vast networks of riparian corridors associated with rivers, streams, and wetlands historically extended from mountains to the ocean. In the Central Valley of California, for example, riparian forests, although highly fragmented today, still support some of the highest net primary productivity of any California ecosystems, and are dominated by trees including species of willow, cottonwood, sycamore, box elder, and valley oak that appear in successional bands created by fluvial processes like flooding and sediment deposition in tension with streambed downcutting, and floodplain dewatering.

CULTURAL SIGNIFICANCE OF OLD GROWTH AND OTHER ECOCULTURAL LEGACIES

Old forests harbor significant ecocultural value across the region, and they are associated with other legacy ecocultural systems, including prairies and other grasslands, woodlands, and wetlands, and features including unique soils with distinctive seed banks. The nonforest areas are a vital complement to the whole forest system. For example, the intermix of open forests, woodlands, savannas, and grasslands provide critical wildlife habitat, which also provide Indigenous and contemporary cultural values for hunting, farming, and other practices relying on open areas; hence, these places were often kept clear with fire.

Places with old and large trees have often been gathering areas for ceremonies and spiritual life, and they served to maintain a sense of cultural identity and belonging to place. Old forest groves are often associated with historical camp areas and family gathering sites for acorn and pine nuts (Schenck & Gifford 1952). Such groves often have ancient names and traditions of stewardship that maintain a sense of place and reciprocal relationships (Vasquez 2019). For instance, ponderosa pine is one of the most prominent of the large and old tree species found in the Southwest and culturally burned with frequent fire (Guiterman et al. 2019), often to cultivate desirable understory species. Notably, Diné have emphasized old ponderosa pines as "grandfather trees" (Yazzie 2007), and Hualapai known as "People of the Tall Pines" actively burned forest stands for large, old ponderosa pine and Gambel oak (Stan et al. 2022).

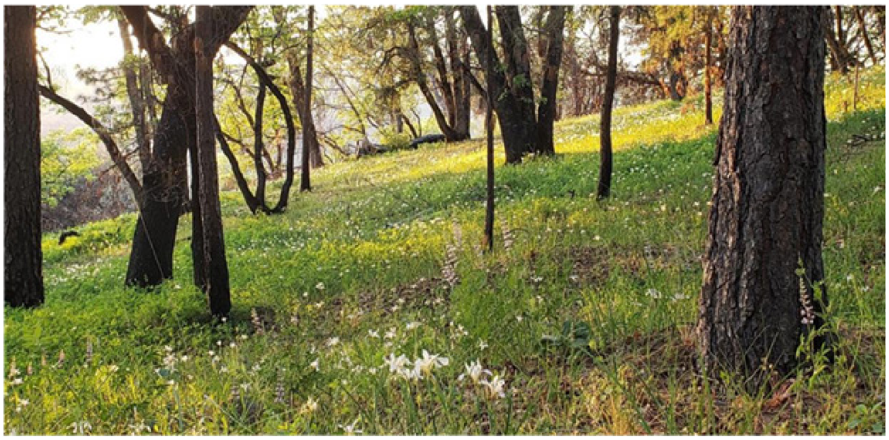

Figure 19. Maintaining California black oak dominance intermixed with ponderosa pine and big leaf maple through culturally-informed prescribed fire at the Big Chico Creek Ecological Reserve that has benefited many ecoculturally important species in the understory. Photo credit Don Hankins.

Many tree species require several decades to produce nuts, and often require 100-200 years or more to become reliable producers. Examples featured in this section include California black oak, Emory oak, and pinyon pine. In the iconic Yosemite Valley, Native people used fire for generations to cultivate black oaks for acorns as a food source (Figure 19) and associated understory plants used for basketry (Vasquez 2019). In Arizona, Western Apache people are currently pursuing more active stewardship of Emory oak groves on national forests to ensure supply of that traditional food in the face of wildfires and other threats (Souther et al. 2021).

Across the Great Basin and Colorado Plateau, Indigenous Peoples today are seeking to conserve pinyon pine, which is both an important food source and a key species for the pinyon jay (Redmond et al. 2023). Fire exclusion, grazing, and other changes have facilitated an expansion of pinyon and juniper woodlands, along with a shift toward older, closed canopy stands (Boone et al. 2018) that are uncharacteristic for these areas in the context of an active fire regime. In some areas, wildfires, droughts, and insect outbreaks have substantially impacted culturally important pinyon groves in what were once open woodland conditions.

Traditional wood products often derive from old or large trees, including logs and planks for canoes, structural timbers for multi-story great houses, poles for teepees, and other construction materials. Several Tribes in the Southwest have sawmills retooled to process smaller logs than when used in construction historically. Tribes continue to use specialty wood products, including logs for constructing hogans and other communal structures. The Mescalero Apache Tribe uses Douglas-fir trees that are 75–100 years old but not particularly large in diameter (Mockta et al. 2018) for teepees.

DEPARTURES IN LANDSCAPE STRUCTURE, FUNCTION, AND COMPOSITION

The impacts of Euro-American colonization in California and the Southwest are unique in comparison with other geographies in North America, owing to the early influence of Spanish colonists that moved north from Mexico in the 1500s (Hämäläinen 2022). Early contact with Russians, Spanish, and English colonizers, followed by imposition of territorial and state governments under the United States, led to significant and early disruptions of fire regimes and ecosystem integrity.

Indigenous Peoples in the region experienced profound mortality and displacement losses, particularly in coastal areas and along major rivers. Surviving communities sought refuge in or inhabited rugged and remote mountainous and drier areas that were isolated and less productive in terms of food and wood. Removal from other parts of their homelands greatly diminished their traditional land stewardship practices, including use of fire and harvesting (Coder et al. 2005).

The imposition of policies that banned Indigenous burning practices altered customary land uses, resulting in devastating and persistent changes to ecological and cultural systems (Hankins 2021; Martinez et al. 2023). Although many Indigenous communities rose above these impacts and often maintained fire regimes into the 20th century, their influence across the region was greatly diminished. In the Southwest, many Tribal Nations retained control over large areas that were part of their ancestral homeland. In California, there are few such large reserves, and the vast majority of Native Nations have limited access and control over small areas and consequently depend on national forests for access to resources within their ancestral homelands.

The impacts of Euro-American colonization on ecosystems in these regions are similar to those in other parts of North America, including clearing of lowland forests and woodlands such as valley oak and riparian areas for agriculture and home sites, harvest of large trees, shifts in species composition and structure, widespread forest densification, woody encroachment into woodlands and openings, and accumulation of heavy fuels, especially in the most productive forest areas (Figure 20). Displacement of Indigenous Peoples, expansion of colonial settlements, and railroad construction were accompanied by livestock grazing. Widespread and persistent overgrazing destroyed organic topsoils and removed the fine fuels that carry fire. Combined with fire exclusion, these factors abruptly disrupted the historical fire regimes and triggered long-term declines in forest health (Swetnam et al. 2016; Taylor et al 2016).

In California's Central Valley, lightning ignitions are generally infrequent, but extensive valley oak and riparian forests were maintained with Indigenous burning in pre-European times. Burning in riparian corridors was traditionally important to maintain access, line of sight, biodiversity, and to maintain culturally important resources (Hankins 2013). Fire, flooding, and sediment deposition events deriving from peak flows were and continue to be essential to maintenance of these riparian corridors but are hindered by fire suppression, dams and sediment capture behind them, and intentional flood control.

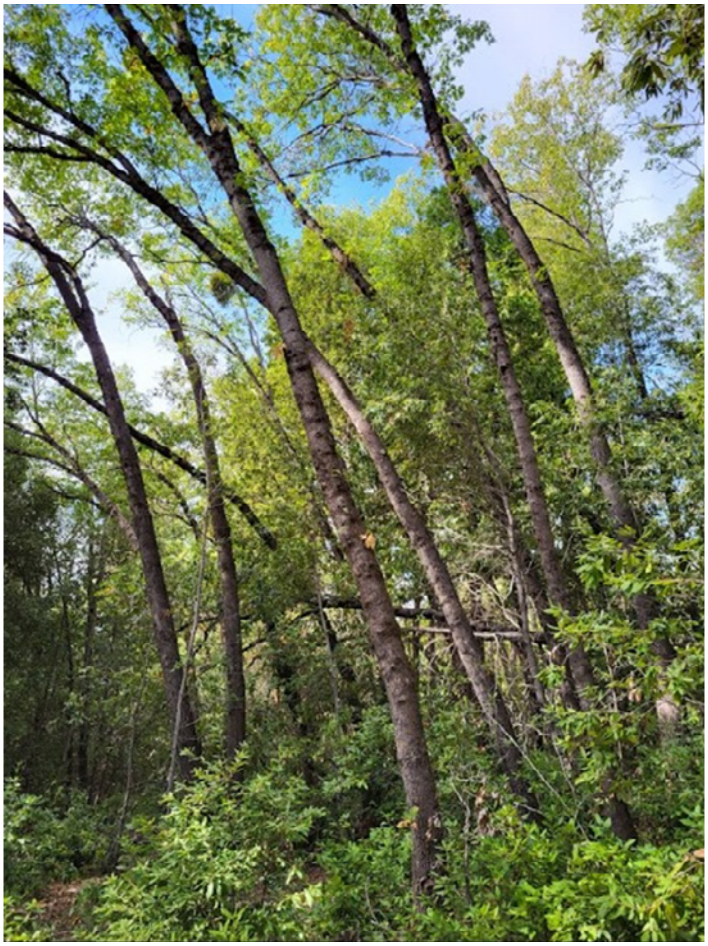

Figure 20. A stand of 120 year-old California black oak trees at the Challenge Experimental Forest in California was thinned at 60 years old to encourage growth of straight boles without lower limbs to make better lumber. Although the trees are now very tall and old, fire exclusion has encouraged trees to lean and become crowded with more shade-tolerant tanoak trees becoming increasingly dominant. Photo credit Jonathan Long.

Cultural impacts of colonialism and land management include declines in large trees, both conifers and hardwoods, and declines in old-forest associated plants and wildlife (e.g., fisher, marten, pileated woodpecker, and spotted owls), many of which have important cultural values. Likewise, the region has experienced a decline of wildlife associated with nuts (e.g., many species, but including band-tailed pigeon), and those associated with forest openings (e.g., elk, deer) and frequent fire, including aspen, cottonwoods, California black oak, and Oregon white oak. Loss of mature and old growth trees has reduced availability of foods and material resources important for sustaining traditional cultures, including nuts, edible plants, basketry materials and medicines, habitat for culturally important species, and specialty wood products needed for canoes and other construction. Damage from large stand-replacing wildfires has also degraded downstream riparian areas and wetlands that are thousands of years old (Long & Davis 2016).

CONTEMPORARY AND EMERGING THREATS

Threats to old forest ecocultural systems and associated values are generally consistent with those in other parts of North America and described for the IWM region. Widespread mortality of old trees, post-fire regeneration failure of ponderosa and Jeffrey pines, and persistent conversion of old conifer forests to hardwoods and nonforest vegetation are among the concerning trends (Guiterman et al. 2022). California's black oak woodlands are widely distributed at middle elevations, but lack of fire and other silvicultural practices in many locations has led to shifts in species dominance from culturally important black oak, tanoak, and sugar pine to ponderosa pine dominance. Acute threats include extreme wildfires, widespread drought and insect mortality, introduced forest diseases, expanding agriculture and land development, and lack of stewardship that emulates cultural practices. Furthermore, synergies among these threats have increased the occurrence of extreme wildfires and the potential for even more devastating wildfires (Safford et al. 2022; Stephens et al. 2022). This reality highlights the need to restore frequent, low-severity fires and hardwood dominance or co-dominance for drought and wildfire resilience.

Climate change and introduction of nonnative species compound impacts of Euro-American colonization in this region. Warming climate will disproportionately impact species in their southernmost latitudes (e.g., aspen, Azpeleta Tarancón et al. 2021), as warming and drying impede seedling establishment and growth and wildfires kill mature trees. In many parts of the region, the spread of nonnative and highly invasive plants (e.g., cheatgrass, buffelgrass, and tamarisk) has amplified changes in fire regimes that now threaten deserts and grasslands, but also woodlands and forests. Introduced pathogens are impacting ecologically and culturally important tree species across the region, including sudden oak death, and blister rust of five-needle pines.

While many species of cultural importance will not go extinct, Indigenous access to them is increasingly difficult. Culturally important hardwood species such as blue oak and California black oak are especially threatened in central and southern California by agriculture and land development, stand-replacing wildfires followed by inadequate regeneration, and expanded insect pests such as the gold-spotted oak borer (Long et al. 2016). Many other oak species, despite adaptations to drought, also appear vulnerable to local extirpation during the next century of intensifying climate change (Brown et al. 2018; Sork et al. 2010; Souther et al. 2021). For example, western Apache Nations in Arizona prize Emory oak acorns as a traditional food source, and they support efforts to reduce threats to Emory oak from severe wildfires, grazing impacts to young trees, groundwater depletion, and climate change (Souther et al. 2021). Similar threats apply to pinyon pine, another keystone ecocultural species for the Washoe Tribe and other Native Nations across the Southwest and Great Basin (Redmond et al. 2023).

Change in land uses from wildland habitats to agricultural and urban development fragment forest and woodland patches, which exacerbates effects of other threats. For example, following Euro-American colonization, the vast majority of valley oak and riparian woodlands of the Central Valley of California were lost to development or agriculture, or left in a degraded condition. Both ecosystems are culturally important and endangered with less than 2 percent of these habitats remaining. Riparian and valley oak woodland habitats are also home to a unique variety of rare species important not only to Indigenous cultures but to global biodiversity as well. Today, the largest extant populations of valley oaks occur in disjunct patches of up to a few hundred acres that are composed of older trees with limited recruitment success. Riparian woodlands are similarly constrained. Given the fragmented nature of small remaining habitat patches, entire groves are at risk to high severity wildfires that are exacerbated by heavy fuel loads and climate variability. These small patches likewise harbor a diminished and declining native floral diversity due to invasive grasses and forbs and small, isolated patch sizes (e.g., Hankins 2013, 2015). The loss of riparian cover and related stream warming also limits the survival of ecoculturally important Chinook salmon. Remaining riparian forests and woodlands at continued risk of wildfires exacerbated by heavy fuel loads and climate variability.

PACIFIC COASTAL FORESTS

Lead authors: C. Eisenberg, K. Nelson, A. Merschel, P. Berrill, T. Vredenburg, C. Beck, A. Russell, M. Nelson, P. Hessburg, T. Chesonis, and T. DeLuca

In Western culture, towering, moss-covered, multi-layered forest canopies and ancient trees have inspired old forests and wilderness archetypes, those apparently unaffected by humans or major disturbances. The grandeur of old trees and forests is often seen as purely a product of vegetation succession through time. Despite this perception, old trees and old forests of the Pacific Coast have been shaped by repeated disturbances, including severe windstorms, snowstorms, landslides, floods, insects and pathogens, and large and small wildfires. Moreover, prior to their forced removal, Indigenous Peoples intentionally stewarded these landscapes with cultural burning and other place-based practices. They sustainably hunted ungulates and harvested food and materials, actively shaping these ecocultural systems to ensure the sustained availability of cultural resources (Lake & Christianson 2019; Long et al. 2021).

Vegetation characteristics and landscape patterns along the Pacific Coast evolved in the context of millennia of active Indigenous stewardship (Dick et al. 2022). The intentional application of fire shaped local-to-landscape-scale forest and nonforest vegetation conditions to benefit humans, with legacies still apparent in the present day. Stewardship practices included leveraging natural disturbance regimes, such as fire, to influence wildlife herbivory patterns, to clear land and transportation routes and create a mosaic of habitat conditions to support a diversity of cultural resources (Kimmerer & Lake 2001).

Indigenous Peoples actively stewarded wildlife and their habitats (Joseph & Turner 2020). They intentionally cultivated desirable plant species and even moved them beyond their natural ranges to improve production and sustainable harvest of wild foods, medicines, and materials (e.g., see Pellatt & Gedalof 2014). Such practices over millennia led to what are now considered historical baseline ecological conditions across much of the region. Ecocultural restoration today continues to mimic vegetation structure and patterns that arose as a result of Indigenous stewardship (Dickson-Hoyle et al. 2022; Gann et al. 2019).

Indigenous Peoples have inhabited the Pacific Coast Region for at least 20,000 years BCE. This area was much later "discovered" by Spanish, British, and Russian expeditions during the 16th-19th centuries. In 1778, Captain Cook explored the Pacific Coast from California to Alaska. The Spanish had been exploring the Pacific Coast as well, from what is today Mexico, north to Alaska. From the late 1700s onward, Euro-Americans established settlements along the Pacific Coast, mainly as fur trading posts. In the Nootka Sound in British Columbia, a trading post was established in 1789. The Russians established a trading post in Sitka, Alaska in 1794. The British Pacific Fur Company established the first permanent European settlement in Oregon at Fort George, now known as Astoria, Oregon, in 1811. The US/Canada border, also known as the "medicine line," was created in 1794 and formally set at the 49th parallel in 1846 (O'Brien 1984).

Euro-American settlement thereafter was strongly incentivized in order to claim these lands and their wealth (e.g., big, old trees and gold) and subdue the remaining Indigenous Peoples who lived there. European exploration and settlement brought devastating disease epidemics, including smallpox and malaria in the late 18th and early 19th centuries, which reduced the Indigenous Population by the mid-1800s by around 90% (Boyd 1990; Scott 1928). Euro-American settlement was accomplished by warfare, genocide, and dispossession of Indigenous Peoples from their land and subsequent removal to reservations, as was specified in treaty language (Berg 2007).

Beyond these devastating impacts, Euro-American settlement created cascading ecological effects (Garibaldi & Turner 2004; Lightfoot et al. 2013). Practices such as cultural burning ended because settlers saw fire as a threat to forests and human infrastructure; engaging in cultural burning became punishable by death. Where cultural burning had been common (e.g., Washington, Oregon, and northern California), cessation of burning practices diminished wildlife habitat (Long et al. 2021). Throughout the Pacific Coast Region, extensive logging and mining further reduced old forests and wildlife habitat. Settlers over-harvested ungulates and furbearing mammals and salmonids to near extinction. The US federal government later dammed rivers, further impeding anadromous fish runs (McClure et al. 2008; Wohl 2021). Returns of native Pacific salmonids today are a small fraction of their historical abundance in inland rivers and streams. Many Pacific Coast Tribes are salmon and acorn People (Norgaard 2019). Loss of once abundant salmon is devastating to the original Peoples of this landscape as is encroachment of conifer forests on once expansive oak woodlands.

MAJOR ECOCULTURAL SYSTEMS

Following the loss of ecocultural stewardship, many landscapes transitioned to dense forest with increasing wildfire hazard, greater susceptibility to drought, closed forest canopies, fewer meadows and prairies, with fewer edible understory plants. In the following sections, we describe the historical structure, composition, and ecocultural stewardship practices employed across three common Pacific Coast biomes: 1) oak prairies and woodlands; 2) inland montane forests; and 3) Pacific maritime forests.

OAK PRAIRIES AND WOODLANDS

Oak prairies and woodlands of the Pacific Coast were historically extensive. They occurred in the relatively warm, dry microclimates in the Puget Lowlands, Umpqua and Willamette Valleys, California Coast Range, and in lower elevations, valleys, low to mid-montane hillslopes of the Klamath Mountains. On warm, dry sites, Douglas-fir forests thrived, with true fir and western hemlock forests on relatively moist sites. However, dense forests were almost entirely excluded by frequent and sometimes annual cultural burning. Indigenous fire stewardship and agricultural practices cultivated abundant food and textile resources in an ecosystem that otherwise would have converted most energy into inedible woody cellulose in the form of trees (Gilsen 2021).

Historical vegetation composition and structure prior to Euro-American colonization were strikingly different than today in major valleys and along rivers. Large open woodlands with a low density of oak, pine, and some Douglas-fir occurred in uplands transitional to montane forests. Regular cultural fires set in the late summer and fall removed tall grasses, which allowed efficient harvest of acorns and reduction of insect pests because infested acorns generally fell to the ground first and were scorched in these fires. These fires also increased the nutrition of cambium harvested from sugar and ponderosa pine and benefited deer and elk by increasing the volume and nutritional value of fall grasses following the return of fall and winter season rain (Boyd 2022; Kimmerer and Lake 2001).

Prairies were burned annually to roast sunflower seeds and remove sticky oils from tarweed (Boyd 2022); tarweed seeds could be eaten whole or ground into flour. Burning and harvesting techniques in seasonally flooded wetlands maintained widely available roots and tubers rich in carbohydrates, including wapato (onion) and camas lily bulbs (Gilsen 2021, and references therein). Gallery forests along rivers that were too wet to burn provided fuel wood and habitat for waterfowl and cover for large herbivores. Edible carbohydrates produced by cultural burning combined with lowland gallery forests created ideal forage and cover for deer and elk (Gilsen 2021). Fall fires were set to aid hunting and harvest of grasshoppers and Columbia white tail deer (Boyd 2022).

Figure 21. Restored Oregon white oak forest in the southwest Cascades, OR. Photo credit Andrew Merschel.

Indigenous Peoples used frequent cultural burning to expand oak woodlands, prairies, and meadows deep into the relatively moist, productive montane Douglas-fir forests of the western Cascades on both sides of the Willamette Valley (Figure 21). Tree-ring records of historical fires and forest conditions document oak woodlands maintained with frequent low-severity burning prior to Euro-American colonization, followed by abrupt shifts to closed-conifer forest after colonization. High above the North Umpqua River prior to 1856, fires in an oak woodland ecosystem with a history of moderate Indigenous use occurred at < 3-year intervals. These fires took place during both dry and moist years, suggesting intentional burning in moist years (Winthrop 1993). After the violent removal of Indigenous Peoples to reservations in 1856, fire frequency declined due to ongoing mortality in the remaining Indigenous population from Euro-American diseases. The few later fires that occurred, burned only in warm, dry years (Merschel 2021). Full cessation of cultural burning occurred in the early 1900s. Thereafter, woodlands historically composed of Oregon white oak and scattered old sugar pine, ponderosa pine, and Douglas-fir rapidly infilled with dense Douglas-fir, developing into the closed-canopy forests of the 20th and 21st centuries. Conifer encroachment and open oak ecosystems following cessation of cultural burning has been recently documented on the Middle Fork of the Willamette River in montane forests (Johnston et al. 2023) and broadly in the Klamath Mountains (Cocking et al. 2012).

Loss of burning, increased presence of nonnative and invasive species, and substantial habitat fragmentation has resulted in population declines and range contractions of native plant and animal species. Nearly 99% of oak prairies and woodlands have been lost or severely impoverished by fire exclusion, farming, timber harvests, plantation forestry, and urbanization. On privately owned lands, remaining oak prairies and woodlands are at risk of development. On federally owned public lands, many oak woodlands and prairies have been lost to conifer forest by continued encroachment and succession in the absence of fire.

Many species associated with these ecocultural systems are now classified as threatened or endangered (Dunwiddie and Bakker 2011; Pellatt and Gedalof 2014). Remaining populations inhabit small, degraded patches and are increasingly vulnerable to extirpation, genetic isolation, and impediments to movement (USFWS 2017). This is especially concerning for some amphibian, reptile, and small-mammal species such as the Oregon spotted frog. Additionally, oak savannas in Washington, Oregon, and California have been classified as one of the most threatened bird habitats in the US (American Bird Conservancy 2006). The current state of oak prairies and woodlands likely provides insufficient habitat for long-term persistence of several native species within this ecocultural system.

INLAND MONTANE FORESTS OF THE PACIFIC COAST REGION

Inland montane forests cover an extensive region on the Pacific Coast, including much of the Klamath Mountains, Coast Range, Western Cascades, Olympic Peninsula, and British Columbia. Douglas-fir is the keystone species forming the backbone of these forests. However, forest structure and tree composition vary substantially with the regional climate, and at finer scales with historical fire regimes shaped by topography, Indigenous fire stewardship, and lightning ignitions.

In relatively warm, dry environments, forests are often a mixture of Douglas-fir with more drought- and fire-tolerant species, including ponderosa pine, sugar pine, and incense-cedar. Dry mixed-conifer forests are most extensive in the Klamath and Siskiyou Mountains and in the southwestern Oregon and northern

Figure 22. Old Douglas-fir and western hemlock forest in the west Cascades, OR. Photo credit Andrew Merschel.

California Cascade Mountains. Dry mixed conifer forests transition to moist forest with increasing elevation and precipitation, supporting a mixture of Douglas-fir and fire- and drought-sensitive species including western hemlock, western redcedar, and Pacific silver fir. Moist mixed conifer forests dominate the Northern Cascades and Coast Ranges, and on the west side of the Olympic Mountains (Figure 22). The central Cascades and Coast Ranges, and the lee and north sides of the Olympics support a mixture of dry and moist Douglas-fir forest types.

Historical fire regimes and forest dynamics are spatially and temporally diverse and may be poorly represented by coarse contemporary characterizations of fire regimes. Early characterizations of historical fire regimes hypothesized that variation in fire frequency was primarily a function of lightning and unusually extreme fire weather; it was assumed that Indigenous ignitions and cultural burning had little influence on historical fire regimes outside Puget Lowlands and the Willamette and Umpqua Valleys (Agee 1991). Ecologists of that period broadly characterized historical fire regimes across the Pacific Coast region using this framing. In the Siskiyou and Klamath Mountains, dry montane mixed-conifer forests with abundant dry season lightning had a frequent mixed-severity fire regime (Agee 1993). Farther north in the Cascades, ecologists reasoned that decreased lightning activity and increased annual precipitation historically limited fires to the coincidence of extreme drought and severe east-wind storm events (Agee 1990). Fires occurring under these conditions in heavy fuels would have extensive patches of high-severity fire—lethal

Figure 23. Historical photo of forest and nonforest patchworks in Olympic National Park, 1936. Photo credit Osborne Panoramas.

to all but the most fire-resistant conifers.

Extensive high-severity fires resulting from extreme east wind events in the late 19th and early 20th century and the recent 2020 Labor Day fires confirm that infrequent high-severity fires are a critical part of the historical fire regime in relatively moist forests (Reilly et al. 2022). At the same time, current models (e.g., LANDFIRE; Rollins 2009) and characterizations of historical fire regimes (Agee 1993; Franklin & Johnson 2012) still substantially underestimate the area influenced by more frequent low- and moderate-severity smaller fires in moist montane Douglas-fir ecosystems (see also Donato et al 2020; Reilly et al. 2021, 2022; Tepley et al. 2013). Several recent dendrochronological studies demonstrate that low and moderate severity fires mediated plant succession and shaped the composition and structure of old trees and forests over large mid- and upper montane areas of the western Oregon Cascades (Johnston et al. 2023, Merschel 2021; Morrison & Swanson 1990; Tepley et al. 2013; Weisberg 2009; Wendell & Zabowski 2010).

IK documents clarify the role of historical fires in moist, productive forest environments. Cultural use of fire to maintain woodlands and prairies was not limited to relatively dry interior valleys; it also extended into montane environments in the Coast and Cascade Ranges. For example, the Sahatpin, Wasco, and Paiute Peoples focused cultural burning in cool, moist environments in the high Cascades to cultivate thinleaf huckleberry (Steen-Adams et al. 2019). Similarly, in the rain-soaked western Olympic Peninsula, fire at < 20-year intervals would be necessary to maintain beargrass meadows and savannas (Figure 23, Shebitz et al. 2009; Storm & Shebitz 2006). Rather than creating open conditions, cultural burning likely took advantage of and maintained open conditions created by infrequent, high-severity forest fires (Mack & McClure 2002) occurring in cool, moist forests during severe east wind-driven fire events (Reilly et al. 2022). Early Euro-American accounts of Indigenous cultural burning in moist Douglas-fir and western hemlock forests describe extensive open nonforest vegetation on the west side of the Oregon Coast Range. Describing the Central Coast Range in the 1840s, Melville Jacobs writes:

> *When they went out hunting, in June or July, the Indians set fire to the mountains in order to keep the country from being covered in brush. There were only scattered trees, very few trees, so that hunting was easier. From Hatchhouse [present day Florence, OR] up to Cape Mt., seven miles along the North Fork [of the present day Siuslaw River], it was all under ashes, deer could be seen then, large and small marshes could be seen where the deer could be caught. It was fine beautiful open country then!!! no brush; every year they set fire to all the brush (Pullen 1996).*

PACIFIC MARITIME FORESTS

The Pacific coastal rainforest biome includes a band of forest adjacent to the Pacific Ocean from central California to southcentral Alaska. Patterns in forest vegetation vary with latitude and along declining temperature and rising precipitation gradients. However, tree regeneration and growth are not limited by precipitation or temperature in this region, resulting in uniquely high productivity environments with structurally complex forests and trees of impressive stature. Forest types across this biome include California's evergreen mixed conifer forests dominated by coast redwood, conifers, and broadleaf trees; Sitka spruce and western hemlock from Oregon through Alaska; and several cedars including western redcedar, Port Orford cedar, and Alaska yellow cedar.

Although it is often assumed that mature and old characteristics once dominated the full extent of this zone, IK and historical photography (Marshall and NARA 2023) suggest that a patchy mosaic of young recently burned forests, nonforest features such as meadows, prairies, and grassy balds, and scattered patches of different-aged forests were historically common from Vancouver, Canada through northern California (Lepofsky et al. 2005). Indigenous Peoples applied varied ecocultural stewardship practices to maintain these diverse and resilient forest conditions, which supported a broad suite of goods and services for local and more distant Indigenous populations. Today, these once diverse and resilient landscapes have been replaced with dense stands of closed-canopy conifer forests. Private industrial lands in this region are currently dominated by dense, intensively managed conifer plantations, while federal lands are dominated by maturing plantations intermixed with mature and old stands. These simplified forest landscapes represent a loss of species cultural resources and are increasingly at risk of high-severity wildfire under climate change.

For millennia prior to Euro-American settlement, Indigenous Peoples used a variety of cultural practices to steward Pacific coastal rainforest ecosystems (Boyd 2022; Hoffman et al. 2016; Lertzman 2009; Shebitz et al. 2009). These practices sustained both nearby marine and terrestrial resources and provided nutritious diets, medicines, and cultural materials for tools, rituals, garments, art, transportation, and construction of infrastructure (Anderson & Lake 2013; Turner et al. 2013). For example, the Tlingit and Haida People cultivated Pacific herring egg laying on western hemlock branches in nearshore environments (Thornton 2015). Herring were a vital subsistence food resource for many coastal tribes (Todd 2017). Vegetation management strategies such as landscape burning, selective dissemination and propagation of desirable plants, and habitat creation and alteration shifted the composition, structure, and geographic patterns of vegetation in ways still seen today (Lepofsky & Lertzman 2008; Turner et al. 2013).

Along the California coast, cultural burning and other stewardship practices historically maintained coastal prairies and fire-adapted hardwoods, including tanoak and black oak, which were important food sources that resprouted after fire, along with pines and cypresses, which have adaptations to fire including serotinous cones. Other conifers including redwood and Douglas-fir co-evolved and developed structurally complex old trees partially due to injuries from lightning fires and Indigenous burning (Brown & Swetnam 1994; Jones & Russell 2015; Lorimer et al. 2009; Sillet & Van Pelt 2007; Stephens & Fry 2005). In the absence of intentional burning, which reduced fuel loads and maintained a diversity of vegetation types with complex overstory tree architectures, Douglas-fir and other conifers widely invaded these highly productive sites and hazardous surface fuels accumulated (Engber et al. 2011).

Northward, the extent of this biome widens in British Columbia, Canada, and southeast Alaska. The proportion of mature and old forests increases steadily with latitude because high year-around precipitation precluded widespread historical burning. Also, the remoteness, difficult terrain, and inaccessibility of these northern forests limited timber management to gentle slopes and lower montane environments. In the perhumid climate of the northern portion of the biome, which includes coastal British Columbia and southeast Alaska, disturbances in western hemlock and Sitka spruce forest are generally small (≤ 1 to 1000 acres), with gaps and patches developing through individual tree mortality, landslides, and blow-down events. Soil development and fine-scale disturbance is often dominated by small pit and mound terrains created when trees tip over. In many spruce stands, trees tend to hold each other up owing to a continuous canopy that reduces surface winds and the strong tendency of individual trees to dewater the area surrounding them by means of shallow but dense fibrous root networks. Hence, when one tree tips over, other nearby spruce often tip as well as soil moisture rapidly increases and soils of the nearby area become saturated.

Fire-return intervals in coastal British Columbia and southeast Alaska can exceed 1000 years between events (Daniels & Gray 2006). Despite the relative lack of lightning ignitions, Indigenous burning was locally applied to clear vegetation around villages and transportation corridors, improve the condition and production of berry patches, and promote cedar establishment and competitive success (Turner et al. 2013). Charcoal records from coastal British Columbia indicate regular fire use over the last 13,000 years, with more frequent burning near First Nations village sites than outlying areas with less habitation (Hoffman et al. 2016). Vegetation surveys and fire-scar records on nearby sites indicate a greater abundance of western redcedar today on sites with historic burning (39 year mean fire interval, Hoffman 2017). Fire scar records cease after 1893, consistent with the cessation of Indigenous burning practices in other areas following Euro-Canadian settlement. Today, silvicultural techniques such as thinning and variable retention harvest are used to improve wildlife habitat, berry harvests, and production of desirable timber species (Crotteau et al. 2023).

Plant diversity is substantially higher today in coastal rainforests of British Columbia that were last stewarded by Indigenous Peoples more than 150 years ago (Armstrong et al. 2021). Resulting vegetation mosaics effectively changed disturbance regimes, including fire seasonality and frequency, in ways that mitigated the hazard of unintended wildfire and accompanying risk to communities (Kimmerer & Lake 2001). These strategies enhance the quality, quantity, and access to plant and animal habitat important for providing wild food and material resources. Further, these activities promote availability of desirable timber species (e.g., cedar) used for construction, transportation (canoes), and basketry and weaving materials.

CONTEMPORARY AND EMERGING THREATS

Dramatic declines in Indigenous populations due to introduced diseases and forced removal in the 19th century resulted in a steep decline in Indigenous stewardship throughout the region. The fire suppression policies that emerged in the early 1900s further exacerbated this loss of Indigenous stewardship. As a result, landscapes that once consisted of diverse mosaics of multi aged forests as well as meadows, prairies, and grassy mountaintop balds were encroached by conifers. Today, many of the conifer forests that established after the forced removal of Indigenous Peoples are now what many would describe as modern mature forests. However, these mature forests represent a departure from the ecocultural conditions that were sustained through generations of proactive Indigenous stewardship. Due to the extremely productive growing conditions in Pacific coast landscapes, departures have resulted in rapid changes and massive accumulations of conifer biomass.

Highly productive coniferous forests, particularly in the form of merchantable trees, were seen as a valuable commodity to Euro-American settlers. Timber harvest was limited in scope until the second World War when gasoline engines and wheeled or tracked vehicles opened previously inaccessible forests and new markets (Robbins 1997). Timber harvest was mostly limited to private lands until the end of WWII, when the post-war housing boom created increasing demand for lumber. At this time, the US Forest Service and Bureau of Land Management timber sale program grew exponentially. Policies of both agencies directed that forests be managed to maximize sustainable harvest levels, but resulted in forestry practices that favored clearcutting followed by the rapid replanting of desirable conifer species, especially Douglas-fir. For unharvested stands and those that were replanted after harvest, the result is the same – areas that were once diverse mosaics of open forest and nonforested areas are now dominated by dense closed-canopy forest.

Emphasis on timber production on federal lands continued into the late 1980s in Oregon and Washington and through 1990s in southeast Alaska after which growing public concern over federal forest management practices and lawsuits ostensibly concerned with the long-term viability of the northern spotted owl and marbled murrelet, resulted in a dramatic shift in federal forest management (Johnson et al 2023). Resulting policies such as the Northwest Forest Plan focused on protecting late-successional and old forest habitats using a reserve-based management approach. This approach generally excluded any significant proactive stewardship that might promote more resilient and diverse assemblage of conditions across the landscape.

While past policies were focused on growing conifers for timber production, the policies that emerged in the late 1980s and early 1990s were focused on creating reserves that would be dedicated to habitat for late-successional species (Davis et al. 2015; Spies et al. 2018, 2019), which would further minimize disturbance and stewardship in those areas. This focus on minimizing disturbance and stewardship had the unintended consequence of precluding ecocultural stewardship and resulting conditions to which many late-successional species are adapted over evolutionarily significant time frames.

Removal of Indigenous Peoples and stewardship practices, intensive timber-focused management, and a shift to reserve-based passive management over large areas have all had the effect of transitioning forest landscapes that were once much more dynamic and diverse into more uniform landscapes that are overstocked, lacking important nonforest elements as well as legacy old trees, and prone to large and severe wildfires. Climate change exacerbates risks posed by simplified forest ecosystems, subjecting them to additional threats of insect outbreaks and disease epidemics (Agne et al. 2018; Dale et al. 2001; Hansen et al. 2000; Ritóková et al. 2016; Weed et al. 2013).

APPENDIX A: PLACE-BASED EXAMPLES

BOREAL/HEMIBOREAL

CURBING THE LOSS OF OLD FORESTS FROM LARGE, HIGH-INTENSITY WILDFIRES IN NORTHERN ROCKIES LANDSCAPES

In hemiboreal areas of the northern Rockies in Alberta, Canada, people have been burning vegetation for millennia for cultural objectives including habitat creation, promotion of medicinal plants and the maintenance of travel corridors. These stewardship practices also provided protection from large wildfires. Indigenous stewardship of fire generally promotes young vegetation stands that diminish the potential for extreme wildfire behavior by reducing biomass loads and encouraging patches of open vegetation and the presence of less-flammable broadleaf trees (Alexander 2010). Although burning was frequent—often annual—it targeted specific areas on a landscape resulting in a mosaic of stands of different ages (Christianson et al. 2022). Lightning also ignited many large wildfires, creating a fire-prone landscape in which most of the old stands are considered 'fire refugia,' patches that have been spared by one or more surrounding wildfires (Rogeau et al. 2018). By virtue of fostering unique assemblages of plants and animals, old forest stands are ecologically important and provide numerous ecosystem services.

Figure A1. Repeat photos from the eastern slopes of the Rocky Mountains of southern Alberta, Canada, showing change in vegetation cover from conifer, hardwood, and mixedwood forest conditions (top, 1914) to conifer dominated (bottom, 2010) conditions. Photo credit Mountain Legacy Project.

The suppression of cultural burning around the turn of the 20th century and policies of aggressive fire suppression, in addition to the concomitant industrial exploitation of the area's forests, have profoundly altered the landscape mosaic of the northern Rockies. Large valleys once dominated by woodlands, grasslands, and shrublands have been extensively replaced by close-canopied conifer forests (Figure A1, Stockdale et al. 2019a). Reports from Indigenous (Christianson et al. 2022) and Western Science (Amoroso et al. 2011; Rogeau et al. 2016) document historically "mixed" fire regimes (i.e., both surface and crown burning). The lack of open vegetation types across the modern landscape, however, has enhanced the potential for large, high-intensity wildfires that often destroy the remaining fire refugia (Stockdale et al. 2019b). Perhaps the most striking example of this phenomenon is the Kenow wildfire that burned in most of the forested cover of Waterton Lakes National Park, Alberta in 2017. Beyond its vast extent, the wildfire was uncommonly severe, leaving very few unburned islands—even burning isolated trees beyond the treeline—and destroying hundreds of refugia forests that were centuries old (Eisenberg et al. 2019).

Changes in the fire regimes of this area over the 20th century have drastically reduced both the proportion of open vegetation types and old forest stands, thereby causing an imbalance in the regional ecology, and exacerbating the wildfire risk to human communities (Arno et al. 2000). To protect and promote old forests in this area, it is insufficient to simply spare old stands from harvesting. Given the landscapes' high likelihood of burning in a future wildfire (Riley et al. 2016), it is necessary to create landscapes that promote resistance and resilience to intense wildfires. Efforts towards this goal have been initiated, combining approaches such as the mechanical removal of heavy fuels (even in national parks), a greater acceptance and use, albeit still modest, of beneficial fire, and the reintroduction of a keystone herbivore, the plains bison, in some areas. Effective conservation of the remaining old forests in the northern Rockies thus requires a multi-faceted strategy that may combine Indigenous and Western forest practices and approaches to burning. The challenge lies in using varied tools in creative ways to meet complex objectives—restoring the resilient mosaic structure of these landscapes which in turn protects old stands from wildfire.

WILDFIRE RISK REDUCTION IN NORTHERN QUÉBEC CULTURAL LANDSCAPES

About 90% of the forests in Canada are on public land and their management is under provincial or territorial jurisdiction. These landscapes were historically stewarded by Indigenous communities, but today federal and provincial management paradigms often exclude Indigenous Knowledge from management methods and decision-making, despite a constitutional requirement for governments to consult and accommodate Indigenous rights. The James Bay Cree (Eeyouch) stand out as a particular case example (Teitelbaum et al. 2024). They signed the first modern treaty in Canada with the federal and provincial governments in 1975 – the James Bay and Northern Quebec Agreement. Three categories of land are now recognized under this agreement. Category I lands cover about 1.5% of Eeyou Istchee (the Cree territory) and correspond to extant Cree communities. The Cree have exclusive hunting, fishing and trapping rights on category II lands (ca. 18.5% of Cree territory) and trapping rights on category III lands (ca. 80% of Cree territory). The provincial government is responsible for forest management on category II and III lands. On Eeyou Istchee lands, the 1980s and 1990s saw a major increase in commercial forestry operations, densification of the road network, and proliferation of non-Indigenous hunting camps. This led the Cree to file an injunction with the provincial courts calling for cessation of forestry operations due to lack of respect for their rights. This prompted negotiations that led to the signing of the so-called "Paix des Braves" Peace of the Braves agreement in 2002, which included a particular forestry regime for Eeyou Istchee, with increased participation of Cree land users in planning. One percent of the land is now under complete protection from forestry operations, and 25% is under a forest management regime aimed at protecting wildlife habitats.

More frequent and severe wildfires are expected in the near future in northern Quebec (including *Eeyou Istchee*) due to more frequent warm and dry weather conditions (Barnes et al. 2023). Record burned areas in the summer of 2023 (more than 3.7 million hectares burned north of the limit of commercial forestry) provide a glimpse into the future (Figure A2). Losses are astounding and many Cree families will not be able to pursue cultural activities (part of Eeyou Pimatseewin – the Cree way of life) on the land for years to come. Indeed, some hunting grounds have burned entirely, and culturally important plant and animal species have died or have deserted the landscape. Indigenous infrastructures were damaged, both tangible (e.g., hunting camps) and intangible (e.g., forest areas where cultural activities take place), notwithstanding the physical and mental health effects of prolonged smoke exposure and evacuations. While tangible infrastructures, both Indigenous and non-Indigenous, are well documented (roads, electricity transmission lines, houses and other buildings, etc.), little is known about intangible infrastructures that are part of cultural landscapes (Bélisle et al. 2021).

Figure A2. A boreal forest in *Eeyou Istchee* shortly after it burned in the summer 2023. Photo credit Guillaume Proulx.

Cree people acknowledge that some forest fires are a natural phenomenon that can have positive effects (on blueberry production and forage for game species such as moose and snowshoe hare). To enhance or control natural forest regeneration, they formerly conducted controlled burns in specific areas in the fall, carefully timing them to coincide with expected rainfall in following days to prevent loss of fire control. In contrast, exceptionally large wildfires are problematic because they pose a threat of forage species regeneration failure and they can simultaneously destroy entire cultural landscapes, hampering the capacity of the Cree to pursue Eeyou Pimatseewin. Adaptive forest stewardship is therefore aimed at increasing the fire and climate resilience of landscapes and communities where possible. Adaptive management planning done in respectful co-stewardship partnerships with Indigenous Peoples is essential – as they possess key cultural knowledge. Cree firefighters and public safety authorities require training, resources, and decision-making authority since they know best where to concentrate efforts to minimize consequences to important resources and conditions.

To protect their hunting camps, Cree land users ask that firebreaks be cut and maintained around their cabins. They also advocate for thinning forest stands and cutting lower branches to limit fire spread and tree torching. Additionally, they call for silvicultural treatments that can increase the area of broadleaf forest, which is less prone to damage by fire. Furthermore, to limit the negative consequences of wildfire, Cree land users ask for a reduction of the intensity of salvage logging, so that forests are given a chance to regenerate naturally. Finally, Cree people ask for a more even distribution of logging operations and protected areas on the land to maintain a better balance between young, mature, and old forests, and to avoid logging operations in protected areas within family territories. A more balanced landscape management approach would provide greater diversity of forest stands across the landscape, thus increasing resilience to wildfire.

EASTERN TEMPERATE

ECOCULTURAL RESTORATION IN PINE-HARDWOOD FORESTS OF THE MENOMINEE TRIBE

Figure A3. Stewardship on the ancestral territory of the Menominee People uses a variety of silvicultural treatments and burning to mimic historical disturbance regimes. Photo credit Menominee Tribe.

The diverse forest types of northern Wisconsin, the ancestral territory of the Menominee People, have experienced widespread change since Euro-American colonization. Historically, Indigenous cultural burning and other stewardship practices maintained mosaics of oak woodland, pine, mixed pine, and oak forest, with interspersed northern and transitional hardwood stands. Widespread clear-cut logging in the 1800s and early 1900s, extremely large, high-intensity fires burning through slash after high-grade logging, and 100+ subsequent years of fire suppression have transformed these landscapes. Fire-excluded landscapes now favor transitional hardwood stands of aspen and birch, and northern hardwood stands of basswood, beech, ash, and maple, with components of eastern hemlock and balsam fir. Fire-exclusion largely diminished pine and oak woodlands. Restoration practices developed and applied by the Menominee Tribe offer an inspiring example of ecocultural restoration in northeastern pine and hardwood forests (Figure A3). The Tribe utilizes a variety of silvicultural approaches, including even- and uneven-aged silvicultural prescriptions, prescribed burning, and passive management to mimic historical and human-influenced disturbance regimes, and moderate fire severity. All management activities are founded on practices of reciprocity and multi-resource management, striving to provide sustained timber products to the Menominee people, while maintaining wildlife habitat, enhancing aesthetics, protecting cultural resources and archaeological sites, and improving soil and water resources. The diversity of forest cover types managed by the Tribe, as well as the use of demonstration sites to test alternative treatments, promotes the adaptability of these forested landscapes under climate change and shifting disturbance regimes.

STRUCTURAL COMPLEXITY ENHANCEMENT AT STEVENSVILLE BROOK RESEARCH AREA

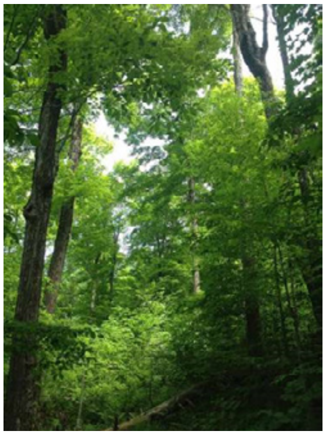

Figure A4. Structural Complexity Enhancement at Stevensville Brook Research Area. Photo credit William Keeton

Eastern hemlock and northern hardwood forests cover vast stretches of the northeastern United States and hold great cultural, economic, and ecological value. Most of these forested landscapes have been intensively managed for timber or agriculture for hundreds of years, leading to significant departures from pre Euro-American colonization structures and compositions. Simplified stand structures that result from clearcut logging and regeneration harvests serve short-term economic needs, but fail to emulate natural disturbances and processes that are critical to the function of these ecosystems. Recent work in the Stevensville Brook Research Area (Figure A4) applied a silvicultural approach called Structural Complexity Enhancement which uses variable density thinning and group selection treatments to better emulate natural disturbances, thereby increasing structural and compositional complexity of these forests. Results suggest that these treatments, while providing ~60% of the economic return of more conventional silvicultural designs, lead to a greater diversity of beneficial outcomes, including improved resilience of large and old trees, and increases in biodiversity, fish and wildlife habitat, and long-term carbon storage. Such treatments represent a proactive management strategy for northeastern hardwood forests that can support their long-term resilience under climate change, while beginning to mend relationships between local communities, Indigenous Peoples, and the surrounding ecosystems.

RED HILLS CONSERVATION LANDS

Figure A5. Red Hills of northern Florida and southern Georgia. Photo credit Morgan Varner.

The 200,000 ha Red Hills of northern Florida and southern Georgia is a unique ecocultural region that retains areas protected from fire-exclusion (Figure A5). Fire was maintained in these habitats for a variety of reasons, but especially to promote habitat for Northern bobwhite, and largely owed to the fact that the lands were in private ownership. The area also harbors several rare examples of old (overstory canopy trees ca. 400 years old or more) upland pine stands with histories of frequent fire (Varner & Kush 2004), such as the Wade Tract and the Larkin Tract. These remnant habitats provide us with a vital lens into the ecosystem's historic composition, structure, and function. These are some of the best examples of old longleaf pine uplands existing today and serve as reference sites for adaptive restoration goals where the landscape has been degraded due to the absence of fire.

The Red Hills landscape is a patchwork of conservation lands with a focus on frequent burning to maintain open savannas and woodlands. Protected areas prioritize Northern bobwhite, but many otherwise rare upland birds (i.e., red-cockaded woodpeckers, Bachman sparrow), reptiles (i.e., gopher tortoise, Eastern diamondback rattlesnakes), and amphibians, along with many listed understory plants thrive under these management practices. The region supports around 100,000 ha of prescribed fire annually (Cummins et al. 2023).

For restoration of fire-excluded pine ecosystems in the region to be successful, it is essential that managers and decision-makers grapple with reintroducing fires into long unburned stands. Where fire has been excluded, structure and composition has changed significantly, away from a grass dominated understory towards mesophytic, hardwood dominated closed canopy woodlands (Varner et al. 2005). The loss of fire in these ecosystems leads to accumulations of deep forest floor fuels that can stress or kill overstory pines when fire occurs. Successful reintroduction of fire requires multiple applications of fire under wet conditions that allow for consumption, but enables the overstory trees to survive and rebuild their resilience (Varner et al. 2007).

WESTERN TEMPERATE

YUROK TERRITORY IN THE KLAMATH BASIN: ADAPTIVE STEWARDSHIP WHERE ECOREGIONS CONVERGE

Figure A6. Douglas-fir trees have encroached into coastal prairies on Yurok lands. Photo credit Joe Hostler, Yurok Tribe.

Yurok ancestral territory includes a mix of the Yurok Reservation, most of which has been allotted and is not owned by Tribal members, and national forest. These lands occur in a transition from wet coastal forests to more mesic interior forests, where fire is an important disturbance mechanism, but where Indigenous burning practices have long been excluded. These lands are within the Klamath basin priority landscape, where the Forest Service is investing in a 10-year wildfire risk reduction strategy, which also strives to conserve old forest.

Conditions desired by cultural practitioners in hardwood groves include having a low density of large oaks with wide-spreading crowns (i.e., open limb structure), potentially intermixed with large conifer trees, but with fewer small understory trees and brush that may hinder collecting and can contribute to increased fuel loading during fire use (Long et al. 2021). Several rounds of thinning are needed to reduce tree density and promote larger, older trees and culturally important hardwoods. These efforts facilitate use of cultural burning and promote resilience to disturbances. The practitioner's approach may result in the majority of cut/harvested-tree volume being in Douglas-fir trees between 25” and 35” diameter at breast height; Tribes may be able to derive revenue from the thinned and removed merchantable “timber” conifers, as a restoration byproduct.

Historical prairie areas, meadows, and forest openings have been lost due to tree encroachment resulting from suppression of wildfire, prohibition of cultural burning, and planting of Douglas-fir (Figure A6). Many of these Douglas-fir trees are quite large in diameter (20-44”+) and height, despite being only 50-70 years old. Restoration of these ecologically important habitats is a priority of the Yurok Tribe’s climate adaptation plan (Sloan & Hostler 2014).

Cultural traditions depend on access to large down logs. Recently, the US Forest Service provided redwood logs from the Redwood/Yurok Research Natural Area following the Tribe’s request of Forest Products for traditional and cultural purposes, under the Forest Service Cultural Heritage and Cooperation Authority. That effort helped the Yurok Tribe to revitalize the tradition of dugout canoe making and associated tourism business (Long et al. 2021).

PAIUTE-JEFFREY PINE-PIAGI SYSTEM

Figure A7. Two old Jeffrey pine trees in the Indiana Summit Research Natural Area. The one on the right has a cleaned and raked piagi trench and incurred less char on the bark following the Clark Fire Photo credit Slaton et al. 2019.

The Indiana Summit Research Natural Area (RNA) provides a distinctive example of Indigenous stewardship in old Jeffrey pine groves in the Eastern Sierra Nevada on the Inyo National Forest. Within this landscape, Paiute people have a tradition of constructing and maintaining trenches around individual trees and using fire to facilitate harvest of a traditional food, the pandora moth larvae (called piagi). The first RNA established in California, Indiana Summit was designated to conserve both old growth Jeffrey pines and the harvesting infrastructure created by Paiute people. A collaborative research project was initiated within the RNA (Slaton et al. 2019) and involved Indigenous elders and youth cleaning the trenches for harvest, which involved raking litter away from the trees. The collaboration had planned to conduct prescribed fire with cultural objectives, but before it could be accomplished, the Clark wildfire burned through most of the RNA in 2016.

The research highlights several important relationships in these ecocultural systems. First, pandora moth eggs appeared more abundant on trees blackened by fire, illustrating how fire plays an important role in the ecocultural system. Second, the tending practices, including raking litter from the base of the trees and trenches, were associated with greater survival of the mature pines when a severe wildfire burned through the area (Figure A7). Third, the crown fire likely did not promote important values as well as a less intense burn would have benefitted the larvae. Even though eggs were observed on the charred bark in 2018, the emerging larvae would not have found green leaves to survive; furthermore, half of the old pine trees had died within seven years after the fire (Slaton et al. 2019).

ANDERSON LAKE BRITISH COLUMBIA

Figure A8. Ecocultural restoration treatments near Anderson Lake, British Columbia. Photo credit Robert Gray.

People of the N’Quatqua First Nation have inhabited the forested landscapes around Andersen Lake in British Columbia’s southern interior for over 4,500 years (Hayden & Ryder 1991). These dry forest landscapes were historically dominated by Douglas-fir and ponderosa pine and, prior to settler colonialism, supported a fire regime characterized by frequent surface fires and low density forests dominated by large, fire-resistant ponderosa pine and Douglas-fir. Cultural burning around Andersen Lake was used to ensure that fires were less disruptive to local communities and to promote more early-seral conditions which supported a diversity of understory plants that were essential to traditional ways of life (Turner et al. 1990; Turner 1989, 1991).

Fire exclusion through loss of cultural burning and active fire suppression allowed landscapes to develop dense forest with accumulated surface and canopy fuels, which has greatly increased fire risk to local communities. In an effort to restore traditional relationships between First Peoples and their landscapes, ecocultural restoration treatments were initiated around Andersen Lake in the late 1990s (Figure A8). Thinning and prescribed burning treatments have reduced understory densities, favored mature and old ponderosa pine and Douglas-fir, and shifted forest structure and species composition toward greater fire-resistance. Stewardship prescriptions, burn sizes, and fire frequencies are guided by oral histories as well as local fire scar records. Collectively, these treatments offer an example of place-based, ecocultural restoration, guided by both IK and WS, that has served to restore the role of people and fire to these landscapes, providing essential cultural values to local communities.

MANAGED WILDFIRE IN ILLILOUETTE CREEK BASIN

Jeffrey pine and mixed-conifer forests of the Illilouette Creek Basin in Yosemite National Park are the ancestral lands of the Southern Sierra Miwuk. Euro-American colonization of the region began during the gold rush of the 1800s and the subsequent federal protection of Yosemite National Park in 1890. Following federal protection, these forests were deprived of what was once widespread cultural burning practices. The Miwuk historically applied fire, and relied on a frequent natural fire regime, to maintain open forest conditions that improved hunting and foraging conditions across the Sierra high country (Anderson 2006). Removal of frequent ground-fires from these forests led to increases in shade tolerant species like white fir and incense cedar, and overall increased likelihood of high-severity fires. Today, high severity fires threaten cultural values cherished by Indigenous Peoples and settlers alike.

Figure A9. Managed wildfire in the Illilouette Creek Basin within Yosemite National Park. Photo credit Zack Steel.

Yosemite was early to adopt a prescribed natural fire program, which in 1972 began permitting most lightning-ignited fires to burn without active suppression (van Wagtendonk 1979). After over four decades of this policy, fire return intervals in the Illilouette Creek Basin are nearing their historical mean (Collins & Stephens 2007) producing low density and heterogeneous forest structures (Chamberlain et al. 2023) dominated by large and old Jeffrey pine and Douglas-fir, with interspersed dry and wet meadows and shrublands. These conditions are more resilient to future fires, droughts, and insect outbreaks, while also enhancing adaptive capacity under a warmer and drier climate. The partial restoration of frequent wildfire to the system has improved ecosystem resilience to severe disturbance, increased water availability in streams, and wildlife habitat relative to nearby areas influenced by continued fire suppression. The most recent 2022 Red Fire to burn through the Illilouette Creek Basin highlights the success of the Park's managed wildfire program, with the fire burning under extreme fire weather conditions yet having mostly low- and moderate-severity effects (Figure A9). Federal protection still prohibits intentional cultural burning in these sites, and the Southern Sierra Miwuk Nation is seeking federal sovereignty rights to allow revival of some traditional fire uses within the Park. The Illilouette Creek Basin represents a model ecosystem, but the lack of restored cultural practices and uses of these landscapes suggests that further work is needed.

EXPLORE MORE PLACE-BASED EXAMPLES OF ADAPTIVE FOREST STEWARDSHIP ONLINE:
adaptiveforeststewardship.org/map

APPENDIX B: TABLES

Table A1. Listed trees included in this report. Continues on next page.

Tree (group)	Common name	Scientific name
ash	green ash	*Fraxinus pennsylvanica*
ash	white ash	*Fraxinus americana*
beech/chestnut	American beech	*Fagus grandifolia*
beech/chestnut	American chestnut	*Castanea dentata*
birch/alder	Alaska paper birch	*Betula neoalaskana*
birch/alder	paper birch	*Betula papyrifera*
birch/alder/hazel	alder	*Alnus spp.*
birch/alder/hazel	hazel	*Corylus spp.*
birch/alder/hazel	beaked hazelnut	*Corylus cornuta*
cedar/juniper	Alaska yellow cedar	*Callitropsis nootkatensis*
cedar/juniper	Atlantic white cedar	*Chamaecyparis thyoides*
cedar/juniper	eastern redcedar	*Juniperus virginiana*
cedar/juniper	juniper	*Juniperus spp.*
cedar/juniper	northern white cedar	*Thuja occidentalis*
cedar/juniper	Port Orford cedar	*Chamaecyparis lawsoniana*
cedar/juniper	western juniper	*Juniperus occidentalis*
cedar/juniper	western redcedar	*Thuja plicata*
cypress	bald cypress	*Taxodium distichum*
cypress	pond cypress	*Taxodium ascendens*
Douglas-fir	Bigcone Douglas-fir	*Pseudotsuga macrocarpa*
Douglas-fir	Douglas-fir	*Pseudotsuga menziesii*
hemlock	eastern hemlock	*Tsuga canadensis*
hemlock	western hemlock	*Tsuga heterophylla*
hickory	bitter pecan	*Carya aquatica*
hickory	hickory	*Carya spp.*
hickory	mockernut hickory	*Carya tomentosa*
hickory	pignut hickory	*Carya glabra*
holly	American holly	*Ilex opaca*
larch	eastern larch (tamarack)	*Larix laricina*
larch	subalpine larch	*Larix lyallii*
larch	western larch	*Larix occidentalis*
magnolia	southern magnolia	*Magnolia grandiflora*

Table A1. Listed trees included in this report. Continued from previous page.

Tree (group)	Common name	Scientific name
magnolia	tulip tree	*Liriodendron tulipifera*
maple	box elder maple	*Acer negundo*
maple	red maple	*Acer rubrum*
oak	Austrian oak	*Quercus cerris*
oak	black oak	*Quercus velutina*
oak	blackjack oak	*Quercus marilandica*
oak	bluejack oak	*Quercus incana*
oak	cabbage palm	*Sabal palmetto*
oak	California black oak	*Quercus kelloggii*
oak	Chapman oak	*Quercus chapmaniii*
oak	cherrybark oak	*Quecus pagoda*
oak	cherrybark oak	*Quercus pagoda*
oak	Darlington oak	*Quercus hemisphaerica*
oak	Emory oak	*Quercus emoryi*
oak	Gambel oak	*Quercus gambelii*
oak	laurel oak	*Quercus laurifolia*
oak	myrtle oak	*Quercus myrtifolia*
oak	overcup oak	*Quercus lyrata*
oak	post oak	*Quercus stellata*
oak	red oak	*Quercus rubra*
oak	sand live oak	*Quercus geminata*
oak	sand post oak	*Quercus margaretta*
oak	scarlet oak	*Quercus coccinea*
oak	southern red oak	*Quercus falcata*
oak	turkey oak	*Quercus laevis*
oak	water oak	*Quercus nigra*
oak	white oak	*Quercus alba*
oak	willow oak	*Quercus phellos*
pine	jack pine	*Pinus banksiana*
pine	Jeffrey pine	*Pinus jeffreyi*
pine	limber pine	*Pinus flexilis*
pine	loblolly pine	*Pinus taeda*
pine	loblolly pine	*Pinus taeda*
pine	lodgepole pine	*Pinus contorta*
pine	longleaf pine	*Pinus palustris*

Table A1. Listed trees included in this report. Continued from previous page.

Tree (group)	Common name	Scientific name
pine	Ocala sand pine	*Pinus clausa var. clausa*
pine	pinyon pine	*Pinus edulis, P. monophylla*
pine	pitch pine	*Pinus rigida*
pine	pond pine	*Pinus serotina*
pine	ponderosa pine	*Pinus ponderosa*
pine	post oak	*Quercus stellata*
pine	shortleaf pine	*Pinus echinata*
pine	slash pine	*Pinus elliottii*
pine	South Florida slash pine	*Pinus densa*
pine	sugar pine	*Pinus lambertiana*
pine	Table mountain pine	*Pinus pungens*
pine	whitebark pine	*Pinus albicaulis*
poplar	bigtooth aspen	*Populus*
poplar	black cottonwood	*Populus balsamifera*
poplar	eastern cottonwood	*Populus deltoides*
poplar	eastern cottonwood	*Populus deltoides*
poplar	Fremont cottonwood	*Populus fremontii*
poplar	poplar	*Populus spp.*
poplar	quaking aspen	*Populus tremuloides*
poplar	quaking aspen	*Populus tremuloides*
redwood	coast redwood	*Sequoia sempervirens*
spruce	black spruce	*Picea mariana*
spruce	Engelmann spruce	*Picea engelmannii*
spruce	Sitka spruce	*Picea sitchensis*
spruce	white spruce	*Picea glauca*
sugarberry/hackberry	sugarberry	*Celtis laevigata*
sycamore	American sycamore	*Plantanus occidentalis*
true fir	balsam fir	*Abies balsamea*
true fir	grand fir	*Abies grandis*
true fir	Pacific silver fir	*Abies amabalis*
true fir	subalpine fir	*Abies lasiocarpa*
true fir	white fir	*Abies concolor*
tupelo/gum	black gum	*Nyssa sylvatica*
tupelo/gum	swamp tupelo	*Nyssa biflora*

Table A1. Listed trees included in this report. Continued from previous page.

Tree (group)	Common name	Scientific name
tupelo/gum	sweetgum	*Liquidambar styraciflua*
tupelo/gum	water tupelo	*Nyssa aquatica*
willow	willow	*Salix spp.*
yew	Florida torreya	*Torreya taxifolia*
yew	Pacific yew	*Taxus brevifolia*

Table A2. Listed shrubs included in this report.

Common name	Species name	Native?
crowberry	*Empetrum spp.*	yes
dwarf palmetto	*Sabal minor*	yes
gallberry	*Ilex glabra, I. coriacea*	yes
huckleberry	*Vaccinium spp.*	yes
saw palmetto	*Serenoa repens*	yes
serviceberry	*Amelanchier*	yes
tamarisk	*Tamarix spp.*	no
thinleaf huckleberry	*Vaccinium membranaceum*	yes

Table A3. Listed herbs included in this report.

Common name	Species name	Native?
balsamroot sunflower	*Balsamorhiza sagittata*	yes
beargrass	*Xerophyllum tenax*	yes
buffelgrass	*Cenchrus ciliaris*	no
camas lily	*Camassia quamash*	yes
cane	*Arundinaria gigantea*	yes
cheatgrass	*Bromus tectorum*	no
Chinese tallow (nonnative)	*Triadica sebifera*	no
cogon grass (nonnative)	*Imperata cylindrica*	no
giant reed (nonnative)	*Arundo spp.*	no
privet (nonnative)	*Ligustrum sinensis*	no
tarweed	*Madia eglans*	yes
wapato	*Sagittaria latifolia*	yes
wiregrass	*Aristida spp.*	yes
wiregrass (Beyrich threeawn grass)	*Aristida beyrichiana*	yes
wiregrass (pineland threeawn)	*Aristida stricta*	yes

Table A4. Listed fish and wildlife included in this report.

Common name	Species name	Native?
American marten	*Martes americana*	yes
beaver	*Castor canadensis*	yes
bison	*Bison bison*	yes
black bear	*Ursus americanus*	yes
Chinook salmon	*Oncorhynchus tshawytscha*	yes
deer	*Odocoileus spp.*	yes
eastern indigo snake	*Drymarchon couperi*	yes
elk (wapati)	*Cervus canadensis*	yes
feral hog	*Sus scrofa*	no
gopher tortoise	*Gopherus polyphemus*	yes
moose	*Alces alces*	yes
mountain goat	*Oreamnos americanus*	yes
mule deer	*Odocoileus hemionus*	yes
nine-banded armadillo	*Dasypus novemcinctus*	no
northern bobwhite	*Colinus virginianus*	yes
Oregon spotted frog	*Rana pretiosa*	yes
Pacific herring	*Clupea pallasii*	yes
pine snake	*Pituophis spp.*	yes
Plains bison	*Bison bison bison*	yes
red-cockaded woodpecker	*Leuconotopicus borealis*	yes
ruffed grouse	*Bonasa umbellus*	yes
snowshoe hare	*Lepus americanus*	yes
white-tailed deer	*Odocoileus virginianus*	yes
wood bison	*Bison bison athabascae*	yes
woodland caribou	*Rangifer tarandus caribou*	yes

LITERATURE CITED

Abatzoglou, J.T., Battisti, D.S., Williams, A.P., Hansen, W.D., Harvey, B.J. & Kolden, C.A. (2021). Projected increases in western US forest fire despite growing fuel constraints. Nature Communications Earth Environment, 2, 1–8.

Abrams, M.D. (1992). Fire and the development of oak forests. BioScience, 42, 346-353.

Abrams, M.D. & Nowacki, G.J. (2020). Native American imprint in palaeoecology. Nature Sustainability, 3, 1-2.

Abrams, M.D., Nowacki, G.J. & Hanberry, B.B. (2021). Oak forests and woodlands as Indigenous landscapes in the Eastern United States. Journal of the Torrey Botanical Society, 149, 101–121.

Agee, J.K. (1990). The historical role of fire in Pacific Northwest forests. In: Natural and Prescribed Fire in Pacific Northwest Forests (eds. Walstad, J.D., Radosevich, S.R. & Sandberg, D.V.). Oregon State University Press, Corvallis, OR.

Agee, J.K. (1991). Fire history of Douglas-fir forests in the Pacific Northwest. In: Wildlife and Vegetation of Unmanaged Douglas-Fir Forests (Gen. Tech. Rep. No. PNW-GTR-285). U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR.

Agee, J.K. (1996). Fire Ecology of Pacific Northwest Forests. Island Press.

Agne, M.C., Beedlow, P.A., Shaw, D.C., Woodruff, D.R., Lee, E.H., Cline, S.P., et al. (2018). Interactions of predominant insects and diseases with climate change in Douglas-fir forests of western Oregon and Washington, U.S.A. Forest Ecology and Management, 409, 317–332.

Ahlgren, C.E. (1976). Regeneration of red pine and white pine following wildfire and logging in northeastern Minnesota. Journal of Forestry, 74, 135–140.

Alexander, H.D., Siegert, C., Brewer, J.S., Kreye, J., Lashley, M.A., McDaniel, J.K., Paulson, A.K., Renninger, H.J. & Varner, J.M. (2021). Mesophication of oak landscapes: evidence, knowledge gaps, and future research. BioScience, 71, 531-542.

Alexander, M.E. (2010). Surface fire spread potential in trembling aspen during summer in the boreal forest region of Canada. The Forestry Chronicle, 86, 200–212.

American Bird Conservancy. (2006). Top 20 most threatened bird habitats in the United States: oak savannah. Bird Conservation, 12–13.

Amoroso, M.M., Daniels, L.D., Bataineh, M. & Andison, D.W. (2011). Evidence of mixed-severity fires in the foothills of the Rocky Mountains of west-central Alberta, Canada. Forest Ecology and Management, 262, 2240–2249.

Anderson, D.G. & Sassaman, K.E. (1996). The Paleoindian and Early Archaic Southeast. University of Alabama Press, Tuscaloosa, AL.

Anderson, K. (2005). Tending the Wild: Native American Knowledge and the Management of California's Natural Resources. University of California Press, Berkeley, CA.

Anderson, M.K. & Lake, F.K. (2013). California Indian ethnomycology and associated forest management. Journal of Ethnobiology, 33, 33–85.

Anderson, M.K. (2006). The use of fire by Native Americans in California. In: Fire in California's Ecosystems (eds. Sugihara, N.G., van Wagtendonk, J., Fites-Kaufman, J., Shaffer, K.E. & Thode, A.E.). University of California Press, Berkely, CA.

Anzinger, D. (2002). Big huckleberry (Vaccinium membranaceum Dougl.) ecology and forest succession, Mt. Hood National Forest and Warm Springs Indian Reservation, Oregon. MS Thesis. Oregon State University, Corvallis, OR.

Armstrong, C.G., Miller, J., McAlvay, A., Ritchie, P.M. & Lepofsky, D. (2021). Historical Indigenous land-use explains plant functional trait diversity. Ecology and Society, 26.

Arthur, M.A., Varner, J.M., Lafon, C., Alexander, H.D., Dey, D.C., Horn, S., et al. (2021). Fire ecology and management in eastern broadleaf and Appalachian forests. In: Fire Ecology and Management: Past, Present, and Future of US Forested Ecosystems (eds. Collins, B. & Greenberg, C.H.). Springer, 105–147.

Asselin, H., Belleau, A. & Bergeron, Y. (2006). Factors responsible for the co-occurrence of forested and unforested rock outcrops in the boreal forest. Landscape Ecology, 21, 271–280.

Asselin, H., Payette, S., Fortin, M.-J. & Vallée, S. (2003). The northern limit of Pinus banksiana Lamb. in Canada: explaining the difference between the eastern and western distributions. Journal of Biogeography, 30, 1709–1718.

Au, T.F., Maxwell, J.T., Novick, K.A., Robeson, S.M., Warner, S.M., Lockwood, B.R., et al. (2020). Demographic shifts in eastern US forests increase the impact of late-season drought on forest growth. Ecography, 43, 1475–1486.

Aukema, J.E., McCullough, D.G., Holle, B.V., Liebhold, A.M., Britton, K. & Frankel, S.J. (2010). Historical accumulation of nonindigenous forest pests in the continental United States. BioScience, 60, 886–897.

Azpeleta Tarancón, A., Sánchez Meador, A.J., Padilla, T., Fulé, P.Z. & Kim, Y.-S. (2021). Trends of forest and ecosystem services changes in the Mescalero Apache Tribal Lands. Ecological Applications, 31, e02459.

Balch, J.K., Bradley, B.A., Abatzoglou, J.T., Nagy, R.C., Fusco, E.J. & Mahood, A.L. (2017). Human-started wildfires expand the fire niche across the United States. Proceedings of the National Academy of Sciences, 114, 2946–2951.

Ballinger, T.J., Bhatt, U.S., Bieniek, P.A., Brettschneider, B., Lader, R.T., Littell, J.S., et al. (2023). Alaska terrestrial and marine climate trends, 1957–2021. Journal of Climate, 36, 4375–4391.

Baltzer, J.L., Day, N.J., Walker, X.J., Greene, D., Mack, M.C., Alexander, H.D., et al. (2021). Increasing fire and the decline of fire adapted black spruce in the boreal forest. Proceedings of the National Academy of Sciences, 118, e2024872118.

Bar-Massada, A., Radeloff, V.C. & Stewart, S.I. (2014). Biotic and abiotic effects of human settlements in the wildland–urban interface. Bioscience, 64, 429-437.

Barnes, C., Boulanger, Y., Keeping, T., Gachon, P., Gillett, N., Boucher, J., et al. (2023). Climate change more than doubled the likelihood of extreme fire weather conditions in Eastern Canada. Imperial College London, Grantham Institute for Climate Change.

Bartlett, C., Marshall, M. & Marshall, A. (2012). Two-eyed seeing and other lessons learned within a co-learning journey of bringing together Indigenous and mainstream knowledges and ways of knowing. Journal of Environmental Studies and Sciences, 2, 331–340.

Barton, A.M. & Keeton, W.S. (2018). Ecology and Recovery of Eastern Old-Growth Forests. Island Press.

Baskin, J.M. & Baskin, C.C. (2000). Vegetation of limestone and dolomite glades in the Ozarks and midwest regions of the United States. Annals of the Missouri Botanical Garden, 87, 286-294.

Bélisle, A.C., Wapachee, A. & Asselin, H. (2021). From landscape practices to ecosystem services: landscape valuation in Indigenous contexts. Ecological Economics, 179, 106858.

Belsky, A.J. & Blumenthal, D.M. (1997). Effects of livestock grazing on stand dynamics and soils in upland forests of the Interior West. Conservation Biology, 11, 315–327.

Belsky, A.J., Matzke, A. & Uselman, S. (1999). Survey of livestock influences on stream and riparian ecosystems in the western United States. Journal of Soil and Water Conservation, 54, 419–431.

Berg, L. (2007). The First Oregonians. Oregon Council for the Humanities.

Bergeron, Y., Cyr, D., Drever, C.R., Flannigan, M., Gauthier, S., Kneeshaw, D., et al. (2006). Past, current, and future fire frequencies in Quebec's commercial forests: implications for the cumulative effects of harvesting and fire on age-class structure and natural disturbance-based management. Canadian Journal of Forest Resources, 36, 2737–2744.

Bergeron, Y., Gauthier, S., Flannigan, M. & Kafka, V. (2004). Fire regimes at the transition between mixedwood and coniferous boreal forest in northwestern Quebec. Ecology, 85, 1916–1932.

Berkes, F. & Davidson-Hunt, I.J. (2006). Biodiversity, traditional management systems, and cultural landscapes: examples from the boreal forest of Canada. International Social Science Journal, 58, 35–47.

Bigelow, S.W., Looney, C.E. & Cannon, J.B. (2021). Hurricane effects on climate-adaptive silviculture treatments to longleaf pine woodland in southwestern Georgia, USA. Forestry: An International Journal of Forest Research, 94, 395–406.

Blumm, M.C. (2010). Present at the creation: The 1910 Big Burn and the formative days of the U.S. Forest Service. Ecology Law Quarterly, 37, 1217.

Boone, J., Ammon, E. & Johnson, K. (2018). Long-term declines in the Pinyon Jay and management implications for piñon–juniper woodlands. In: Trends and Traditions: Avifaunal Change in Western North America (eds. Shuford, W.D., Gill Jr, R.E. & Handel, C.M.). 190–197.

Booth, R.K., Schuurman, G.W., Lynch, E.A., Huff, M.G., Bebout, J.A. & Montano, N.M. (2023). Paleoecology provides context for conserving culturally and ecologically important pine forest and barrens communities. Ecological Applications, 33, e2901.

Bouchard, M., Kneeshaw, D. & Messier, C. (2007). Forest dynamics following spruce budworm outbreaks in the northern and southern mixedwoods of central Quebec. Canadian Journal of Forest Research, 37, 763–772.

Boucher, D., Gauthier, S., Thiffault, N., Marchand, W., Girardin, M. & Urli, M. (2020). How climate change might affect tree regeneration following fire at northern latitudes: a review. New Forests, 51, 543–571.

Boucher, P.B., Paynter, I., Orwig, D.A., Valencius, I. & Schaaf, C. (2021). Sampling forests with terrestrial laser scanning. Annals of Botany, 128, 689–708.

Boulanger, Y., Gauthier, S. & Burton, P.J. (2014). A refinement of models projecting future Canadian fire regimes using homogeneous fire regime zones. Canadian Journal of Forest Research, 44, 365–376.

Bowman, D.M.J.S., Perry, G.L.W., Higgins, S.I., Johnson, C.N., Fuhlendorf, S.D. & Murphy, B.P. (2016). Pyrodiversity is the coupling of biodiversity and fire regimes in food webs. Philosophical Transactions of the Royal Society B: Biological Sciences, 371, 20150169.

Boyd, C.S. (2022). Managing for resilient sagebrush plant communities in the modern era: we're not in 1850 anymore. Rangelands, 44, 167–172.

Boyd, I.L., Freer-Smith, P.H., Gilligan, C.A. & Godfray, H.C.J. (2013). The consequence of tree pests and diseases for ecosystem services. Science, 342(6160), 1235773.

Boyd, R. (Ed.). (1999). Indians, Fire, and the Land in the Pacific Northwest, 1st Edition. Oregon State University Press, Corvallis, OR.

Boyd, R.T. (1990). Demographic History, 1774-1874. In: Handbook of North American Indians, Volume 7: Northwest Coast (eds. Suttles, W. & Sturtevant, W.). Smithsonian Institution Scholarly Press, Washington, DC, 135–148.

Brandt, L., He, H., Iverson, L., Thompson, F.R., Butler, P., Handler, S., Janowiak, M., Shannon, P.D., Swanston, C., Albrecht, M. & Blume-Weaver, R. (2014). Central hardwoods ecosystem vulnerability assessment and synthesis: a report from the Central Hardwoods Climate Change Response Framework project. (Gen. Tech. Rep. No. NRS-124). US Department of Agriculture, Forest Service, Northern Research Station, Newtown Square, PA.

Brown, B.J., McLaughlin, B.C., Blakey, R.V. & Morueta-Holme, N. (2018). Future vulnerability mapping based on response to extreme climate events: dieback thresholds in an endemic California oak. Diversity and Distributions, 24, 1186–1198.

Brown, C.D. & Johnstone, J.F. (2012). Once burned, twice shy: repeat fires reduce seed availability and alter substrate constraints on Picea mariana regeneration. Forest Ecology and Management, 266, 34–41.

Brown, P.M. & Swetnam, T.W. (1994). A cross-dated fire history from coast redwood near Redwood National Park, California. Canadian Journal of Forest Research, 24, 21–31.

Brubaker, L.B. (1991). Climate change and the origin of old-growth Douglas-fir forests in the Puget Sound lowland. In: Wildlife and Vegetation of Unmanaged Douglas-fir Forests (Gen. Tech. Rep. No. PNW-GM-285). U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR.

Burrell, A.L., Cooperdock, S., Potter, S., Berner, L.T., Hember, R., Macander, M.J., et al. (2024). The predictability of near- term forest biomass change in boreal North America. Ecosphere, 15, e4737.

Burton, P.J., Parisien, M.-A., Hicke, J.A., Hall, R.J. & Freeburn, J.T. (2008). Large fires as agents of ecological diversity in the North American boreal forest. International Journal of Wildland Fire, 17, 754–767.

Calkin, D.E., Cohen, J.D., Finney, M.A. & Thompson, M.P. (2014). How risk management can prevent future wildfire disasters in the wildland-urban interface. Proceedings of the National Academy of Sciences, 111, 746–751.

Calkin, D.E., Thompson, M.P. & Finney, M.A. (2015). Negative consequences of positive feedbacks in US wildfire management. Forest Ecosystems, 2, 9.

Callicott, J.B. & Nelson, M.P. (Eds.). (1998). The Great New Wilderness Debate. University of Georgia Press, Athens, GA.

Carlson, A.R., Helmers, D.P., Hawbaker, T.J., Mockrin, M.H. & Radeloff, V.C. (2022). The wildland–urban interface in the United States based on 125 million building locations. Ecological Applications, 32, e2597.

Carroll, S.R., Garba, I., Figueroa-Rodríguez, O.L., Holbrook, J., Lovett, R., Materechera, S., et al. (2020). The CARE principles for Indigenous data governance, Data Science Journal 19, 43.

Chamberlain, C.P., Cova, G.R., Cansler, C.A., North, M.P., Meyer, M.D., Jeronimo, S.M.A., et al. (2023). Consistently heterogeneous structures observed at multiple spatial scales across fire-intact reference sites. Forest Ecology and Management, 550, 121478.

Chavardès, R.D., Danneyrolles, V., Portier, J., Girardin, M.P., Gaboriau, D.M., Gauthier, S., et al. (2022). Converging and diverging burn rates in North American boreal forests from the Little Ice Age to the present. International Journal of Wildland Fire, 31, 1184–1193.

Christianson, A.C., Sutherland, C.R., Moola, F., Gonzalez Bautista, N., Young, D. & MacDonald, H. (2022). Centering Indigenous voices: the role of fire in the boreal forest of North America. Current Forestry Reports, 8, 257–276.

Churchill, D.J., Jeronimo, S.M.A., Hessburg, P.F., Cansler, C.A., Povak, N.A., Kane, V.R., et al. (2022). Post-fire landscape evaluations in Eastern Washington, USA: assessing the work of contemporary wildfires. Forest Ecology and Management, 504, 119796.

Churchill, E. (2005). Environmental degradation and human well-being: report of the millennium ecosystem assessment. Population and Development Review, 31.

Clarkson, L., Morrissette, V. & Régallet, G. (1992). Our Responsibility to the Seventh Generation: Indigenous Peoples and Sustainable Development. International Institute for Sustainable Development, Winnipeg.

Clayton, L.A., Moore, E.C. & Knight, V.J. (Eds.). (1995). The De Soto Chronicles Vol 1 & 2: The Expedition of Hernando de Soto to North America in 1539-1543. University of Alabama Press, Tuscaloosa, AL.

Climate Adaptation Plan. (2022). No. FS-1196. U.S. Department of Agriculture Forest Service, Washington Office, Washington, DC.

Cocking, M.I., Varner, J.M. & Sherriff, R.L. (2012). California black oak responses to fire severity and native conifer encroachment in the Klamath Mountains. Forest Ecology and Management, 270, 25–34.

Coder, C., Randall, V., Smith-Rocha, E. & Hines, R. (2005). Chi ch'il (acorns): dissolution of traditional Dilzhe'e gathering practice(s) due to federal control of the landscape. In: Proceedings of Connecting Mountain Islands and Desert Seas: Biodiversity and Management of the Madrean Archipelago II (Conf. Proc. No. RMRS-P-36). U.S. Department of Agriculture Forest Service, Rocky Mountain Research Station, Fort Collins, CO.

Colenbaugh, C. & Hagan, D.L. (2023). After the fire: potential impacts of fire exclusion policies on historical Cherokee culture in the southern Appalachian Mountains, USA. Human Ecology, 51, 291-301.

Collins, B.M. & Stephens, S.L. (2007). Fire scarring patterns in Sierra Nevada wilderness areas burned by multiple wildland fire use fires. Fire Ecology, 3, 53–67.

Cook, B.I., Miller, R.L. & Seager, R. (2009). Amplification of the North American "Dust Bowl" drought through human-induced land degradation. Proceedings of the National Academy of Sciences, 106, 4997–5001.

Coop, J.D., Parks, S.A., Stevens-Rumann, C.S., Crausbay, S.D., Higuera, P.E., Hurteau, M.D., et al. (2020). Wildfire-driven forest conversion in western North American landscapes. BioScience, 70, 659–673.

Coop, J.D., Parks, S.A., Stevens-Rumann, C.S., Ritter, S.M. & Hoffman, C.M. (2022). Extreme fire spread events and area burned under recent and future climate in the western USA. Global Ecology and Biogeography, 31, 1949–1959.

Copes-Gerbitz, K., Hagerman, S.M. & Daniels, L.D. (2021). Situating Indigenous knowledge for resilience in fire-dependent social-ecological systems. Ecology and Society, 26, 25.

Coppoletta, M., Merriam, K.E. & Collins, B.M. (2016). Post-fire vegetation and fuel development influences fire severity patterns in reburns. Ecological Applications, 26, 686–699.

Costanza, J.K., Terando, A.J., McKerrow, A.J. & Collazo, J.A. (2015). Modeling climate change, urbanization, and fire effects on Pinus palustris ecosystems of the southeastern U.S. Journal of Environmental Management, 151, 186–199.

Cova, G., Kane, V.R., Prichard, S., North, M. & Cansler, C.A. (2023). The outsized role of California's largest wildfires in changing forest burn patterns and coarsening ecosystem scale. Forest Ecology and Management, 528, 120620.

Covington, W.W. & Moore, M.M. (1994). Southwestern ponderosa forest structure: changes since Euro-American settlement. Journal of Forestry, 92, 39–47.

Cronon, W. (1992). Nature's Metropolis: Chicago and the Great West. Norton, New York.

Crotteau, J.S., Besse, W.J., Berrill, J.-P., Deal, R.L., Harrington, C.A. & Nelson, K.N. (2023). Ecological silviculture for North American pacific coastal temperate rainforests. In: Ecological Silvicultural Systems: Exemplary Models for Sustainable Forest Management (eds. Palik, B.J. & D'Amato, A.W.). John Wiley & Sons, 199–212.

Cummins, K., Noble, J., Varner, J.M., Robertson, K.M., Hiers, J.K., Nowell, H.K., et al. (2023). The southeastern U.S. prescribed fire permit database: hot spots and hot moments in prescribed fire across the southeastern U.S.A. Fire, 6, 372.

Dale, V.H., Joyce, L.A., McNulty, S., Neilson, R.P., Ayres, M.P., Flannigan, M.D., et al. (2001). Climate change and forest disturbances: climate change can affect forests by altering the frequency, intensity, duration, and timing of fire, drought, introduced species, insect and pathogen outbreaks, hurricanes, windstorms, ice storms, or landslides. BioScience, 51, 723–734.

Daniels, L.D. & Gray, R.W. (2006). Disturbance regimes in coastal British Columbia. Journal of Ecosystems and Management, 7, 2.

Danneyrolles, V., Cyr, D., Girardin, M.P., Gauthier, S., Asselin, H. & Bergeron, Y. (2021). Influences of climate fluctuations on northeastern North America's burned areas largely outweigh those of European settlement since AD 1850. Environmental Research Letters, 16, 114007.

Daschuk, J. (2019). Disease, politics of starvation, and the loss of Indigenous life. In: Clearing the Plains. University of Regina Press, Saskatchewan, Canada.

Davidson-Hunt, I. & Berkes, F. (2003). Learning as you journey: Anishinaabe perception of social-ecological environments and adaptive learning. Conservation Ecology, 8.

Davis, K.T., Dobrowski, S.Z., Higuera, P.E., Holden, Z.A., Veblen, T.T., Rother, M.T., et al. (2019). Wildfires and climate change push low-elevation forests across a critical climate threshold for tree

regeneration. Proceedings of the National Academy of Sciences, 116, 6193–6198.
Davis, M.B. (1983). Quaternary history of deciduous forests of eastern North America and Europe. Annals of the Missouri Botanical Garden, 70, 550-563.
Davis, M.B. (1989). Lags in vegetation response to greenhouse warming. Climatic Change, 15, 75–82.
Davis, R.J., Ohmann, J.L., Kennedy, R.E., Cohen, W.B., Gregory, M.J., Yang, Z., et al. (2015). Northwest Forest Plan–the first 20 years (1994-2013): status and trends of late-successional and old-growth forests (Gen. Tech. Rep. No. PNW-GTR-911). U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR.
Delcourt, H. R. and Delcourt, P.A. (1981). Vegetation maps for eastern North America 40,000 years ago to the present. In: Romans, R.C. (ed). Geobotany II. Plenum. New York, New York, USA, 123–165.
Delcourt, H.R. & Delcourt, P.A. (1997). Pre-Columbian Native American use of fire on southern Appalachian landscapes. Conservation Biology, 11, 1010–1014.
DeLuca, T.H. & Hatten, J.A. (2024). Conservation from the bottom up: a forestry case study. Anthropocene, 45, 100423.
DeLuca, T.H., Pingree, M.R.A. & Gao, S. (2019). Assessing soil biological health in forest soils. In: Developments in Soil Science, Global Change and Forest Soils (eds. Busse, M., Giardina, C.P., Morris, D.M. & Page-Dumroese, D.S.). 36, 397–426.
DeLuca, T.H., Zackrisson, O., Nilsson, M.-C. & Sellstedt, A. (2002). Quantifying nitrogen-fixation in feather moss carpets of boreal forests. Nature, 419, 917–920.
D'Evelyn, S.M., Jung, J., Alvarado, E., Baumgartner, J., Caligiuri, P., Hagmann, R.K., et al. (2022). Wildfire, smoke exposure, human health, and environmental justice need to be integrated into forest restoration and management. Current Environmental Health Reports, 9, 366–385.
Dey, D.C. (2014). Sustaining oak forests in eastern North America: regeneration and recruitment, the pillars of sustainability. Forest Science, 60, 926–942.
Dick, C.A., Sewid-Smith, D., Recalma-Clutesi, K., Deur, D. & Turner, N.J. (2022). "From the beginning of time": The colonial reconfiguration of native habitats and Indigenous resource practices on the British Columbia Coast. FACETS, 7, 543–570.
Dickson-Hoyle, S., Ignace, R.E., Ignace, M.B., Hagerman, S.M., Daniels, L.D. & Copes-Gerbitz, K. (2022). Walking on two legs: a pathway of Indigenous restoration and reconciliation in fire-adapted landscapes. Restoration Ecology, 30, e13566.
Dietz, M.S., Barnett, K., Belote, R.T. & Aplet, G.H. (2021). The importance of U.S. national forest roadless areas for vulnerable wildlife species. Global Ecology and Conservation, 32, e01943.
Dodd, W., Scott, P., Howard, C., Scott, C., Rose, C., Cunsolo, A., et al. (2018). Lived experience of a record wildfire season in the Northwest Territories, Canada. Canadian Journal of Public Health, 109, 327–337.
Donato, D.C., Halofsky, J.S. & Reilly, M.J. (2020). Corralling a black swan: natural range of variation in a forest landscape driven by rare, extreme events. Ecological Applications, 30, e02013.
Du, H., Alexander, L.V., Donat, M.G., Lippmann, T., Srivastava, A., Salinger, J., Kruger, A., Choi, G., He, H.S., Fujibe, F. & Rusticucci, M. (2019). Precipitation from persistent extremes is increasing in most regions and globally. Geophysical Research Letters, 46, 6041-6049.
Dunbar-Ortiz, R. (2021). Not "A Nation of Immigrants": Settler Colonialism, White Supremacy, and a History of Erasure and Exclusion. Beacon Press.
Dunwiddie, P., Foster, D., Leopold, D. & Leverett, R.T. (1996). Old-growth forests of southern New England, New York, and Pennsylvania. In: Eastern Old-growth Forests: Prospects for Rediscovery and Recovery. Island Press, Washington, DC, 126–143.
Dunwiddie, P.W. & Bakker, J.D. (2011). The future of restoration and management of prairie-oak ecosystems in the Pacific Northwest. Northwest Science, 85, 83–92.
Duveneck, M.J. & Scheller, R.M. (2015). Climate-suitable planting as a strategy for maintaining forest productivity and functional diversity. Ecological Applications, 25, 1653–1668.
Dyrness, Viereck, L.A. & van Cleve, K. (1986). Fire in taiga communities of interior Alaska. In: Forest ecosystems in the Alaskan taiga: a synthesis of structure and function. Springer New York, New York, NY, 74–86.
Egan, T. (2009). The Big Burn: Teddy Roosevelt and the Fire that Saved America. Houghton Mifflin Harcourt, Boston, MA.
Eisenberg, C., Anderson, C.L., Collingwood, A., Sissons, R., Dunn, C.J., Meigs, G.W., et al. (2019). Out of the ashes: ecological resilience to extreme wildfire, prescribed burns, and Indigenous burning in ecosystems. Frontiers in Ecology and Evolution, 7.
Elliott, K.J., & Vose, J.M. (2011). The contribution of the Coweeta Hydrologic Laboratory to developing an understanding of long-term (1934–2008) changes in managed and unmanaged forests. Forest Ecology and Management 261, 900–910
Ellis, P.W., Page, A.M., Wood, S., Fargione, J., Masuda, Y.J., Carrasco Denney, V., et al. (2024). The principles of natural climate solutions. Nature Communications, 15, 547.
Ellison, A.M., Bank, M.S., Clinton, B.D., Colburn, E.A., Elliott, K., Ford, C.R., et al. (2005). Loss of foundation species: consequences for the structure and dynamics of forested ecosystems. Frontiers in Ecology and the Environment, 3, 479–486.
Elsner, J.B., Kossin, J.P. & Jagger, T.H. (2008). The increasing intensity of the strongest tropical cyclones. Nature, 455, 92–95.
Emanuel, K.A. (2013). Downscaling CMIP5 climate models shows increased tropical cyclone activity over the 21st century. Proceedings of the National Academy of Sciences, 110, 12219–12224.
Engber, E.A., Varner, J.M., Arguello, L.A. & Sugihara, N.G. (2011). The effects of conifer encroachment and overstory structure on fuels and fire in an oak woodland landscape. Fire Ecology, 7, 32–50.
Engstrom, R.T. (1993). Characteristic mammals and birds of longleaf pine forests. In: Proceedings of the Tall Timbers Fire Ecology Conference (ed. Hermann, S.M.). Tall Timbers Research Station, Tallahassee, FL, 127–138.
Environment and Climate Change Canada. (2023). Available at: https://www.canada.ca/en/environment-climate-change/services/climate-change/science-research-data/climate-trends-variability/adjusted-homogenized-canadian-data.html. Last accessed 23 February 2024.
Everett, R., Schellhaas, R., Ohlson, P., Spurbeck, D. & Keenum, D. (2003). Continuity in fire disturbance between riparian and

adjacent sideslope Douglas-fir forests. Forest Ecology and Management, 175, 31–47.
Falk, D.A., Heyerdahl, E.K., Brown, P.M., Farris, C., Fulé, P.Z., McKenzie, D., et al. (2011). Multi-scale controls of historical forest-fire regimes: new insights from fire-scar networks. Frontiers in Ecology and the Environment, 9, 446–454.
Falk, D.A., van Mantgem, P.J., Keeley, J.E., Gregg, R.M., Guiterman, C.H., Tepley, A.J., et al. (2022). Mechanisms of forest resilience. Forest Ecology and Management, 512, 120129.
Falk, D.A., Watts, A.C. & Thode, A.E. (2019). Scaling ecological resilience. Frontiers in Ecology and Evolution, 7.
Fei, S., Morin, R.S., Oswalt, C.M. & Liebhold, A.M. (2019). Biomass losses resulting from insect and disease invasions in US forests. Proceedings of the National Academy of Sciences, 116, 17371–17376.
Feir, D..L., Gillezeau, R. & Jones, M.E.C. (2022). The Slaughter of the Bison and Reversal of Fortunes on the Great Plains. Working Paper Series, National Bureau of Economic Research.
Flatley, W., Bragg, L. & Bragg, D. (2023). Dynamic fire regimes and forest conditions across three centuries in a shortleaf pine-oak forest in the Ouachita Mountains, Arkansas, USA. Annals of the American Association of Geographers, 113, 1–18.
Flatley, W.T., Lafon, C.W., Grissino-Mayer, H.D. & LaForest, L.B. (2013). Fire history, related to climate and land use in three southern Appalachian landscapes in the eastern United States. Ecological Applications, 23, 1250-1266.
Foster, D.E., Battles, J.J., Collins, B.M., York, R.A. & Stephens, S.L. (2020). Potential wildfire and carbon stability in frequent-fire forests in the Sierra Nevada: trade-offs from a long-term study. Ecosphere, 11, e03198.
Foster, D.R., Motzkin, G. & Slater, B. (1998). Land-use history as long-term broad-scale disturbance: regional forest dynamics in central New England. Ecosystems, 1, 96–119.
Franklin, J.F. & Johnson, K.N. (2012). A restoration framework for federal forests in the Pacific Northwest. Journal of Forestry, 110, 429–439.
Fraser, J.S., Pile Knapp, L.S., Graham, B., Jenkins, M.A., Kabrick, J., Saunders, M., Spetic, M. & Shifley. (2023). Carbon dynamics in old-growth forests of the central hardwoods region, USA. Forest Ecology and Management, 537, 120958.
Freeman, J.E. & Kobziar, L.N. (2011). Tracking postfire successional trajectories in a plant community adapted to high-severity fire. Ecological Applications, 21, 61–74.
Frelich, L., Lorimer, C. & Stambaugh, M. (2021). History and future of fire in hardwood and conifer forests of the Great Lakes-northeastern forest region, USA. Fire Ecology and Management: Past, Present, and Future of US Forested Ecosystems, 39, 243–285.
Frelich, L.E. & Reich, P.B. (1996). Old growth in the Great Lakes region. In: Eastern Old-Growth Forests: Prospects For Rediscovery and Recovery (ed. Davis, M.B.). Island Press, pp. 144–160.
Frelich, L.E. & Reich, P.B. (2009). Wilderness conservation in an era of global warming and invasive Species: a case study from Minnesota's Boundary Waters Canoe Area Wilderness. Natural Areas Journal, 29, 385–393.
Fowler, C. & Konopik, E. (2007). The history of fire in the southern United States. Human Ecology Review, 14, 165-176.
Gaboriau, D.M., Chaste, É., Girardin, M.P., Asselin, H., Ali, A.A., Bergeron, Y., et al. (2023). Interactions within the climate-vegetation-fire nexus may transform 21st century boreal forests in northwestern Canada. iScience, 26, 106807.
Gaines, W.L., Hessburg, P.F., Aplet, G.H., Henson, P., Prichard, S.J., Churchill, D.J., et al. (2022). Climate change and forest management on federal lands in the Pacific Northwest, USA: managing for dynamic landscapes. Forest Ecology and Management, 504, 119794.
Gann, G.D., McDonald, T., Walder, B., Aronson, J., Nelson, C.R., Jonson, J., et al. (2019). International principles and standards for the practice of ecological restoration. Second edition. Restoration Ecology, 27, S1–S46.
Gao, P., Terando, A.J., Kupfer, J.A., Morgan Varner, J., Stambaugh, M.C., Lei, T.L., et al. (2021). Robust projections of future fire probability for the conterminous United States. Science of The Total Environment, 789, 147872.
Gao, Y., Huang, W., Yu, P., Xu, R., Yang, Z., Gasevic, D., et al. (2023). Long-term impacts of non-occupational wildfire exposure on human health: A systematic review. Environmental Pollution, 320, 121041.
Gardiner, B.A. & Quine, C.P. (2000). Management of forests to reduce the risk of abiotic damage — a review with particular reference to the effects of strong winds. Forest Ecology and Management, 135, 261–277.
Garibaldi, A. & Turner, N. (2004). Cultural keystone species: implications for ecological conservation and restoration. Ecology and Society, 9.
Gibson, C.M., Brinkman, T., Cold, H., Brown, D. & Turetsky, M. (2021). Identifying increasing risks of hazards for northern land-users caused by permafrost thaw: integrating scientific and community-based research approaches. Environmental Research Letters, 16, 064047.
Gibson, C.M., Chasmer, L.E., Thompson, D.K., Quinton, W.L., Flannigan, M.D. & Olefeldt, D. (2018). Wildfire as a major driver of recent permafrost thaw in boreal peatlands. Nature Communications, 9, 3041.
Gilland, K.E. & McCarthy, B.C. (2012). Reintroduction of American chestnut (Castanea dentata) on reclaimed mine sites in Ohio: microsite factors controlling establishment success. Northern Journal of Applied Forestry, 29, 197-205.
Gilliam, F.S. (2021). Impacts of tropical cyclones on longleaf pine ecosystems of Florida: tropical cyclogenesis, landfall frequencies, and climate change. Frontiers in Ecology and Evolution, 9.
Gilsen, L. (2021). Pyroculture - Kalapuya and the Land: What Did the Willamette Valley Look Like When the Indians Lived There? Oregon Archaeology. Available at: http://www.oregon-archaeology.com/theory/pyroculture/. Last accessed 5 February 2024.
Gray, A.N., Pelz, K., Hayward, G.D., Schuler, T., Salverson, W., Palmer, M., Schumacher, C., & Woodall, C.W. (2023). Perspectives: The wicked problem of defining and inventorying mature and old-growth forests. Forest Ecology and Management, 546, 121350.
Grossmann, E.B. & Mladenoff, D.J. (2007). Open woodland and savanna decline in a mixed-disturbance landscape (1938 to 1998) in the Northwest Wisconsin (USA) Sand Plain. Landscape Ecology, 22, 43–55.
Guillermo, P.M., Perera, A.H., Peterson, U. & Iverson, L.R. (2018).

Ecosystem services from forest landscapes: an overview. In: Ecosystem Services from Forest Landscapes: Broadscale Considerations (eds. Perera, A.H., Peterson, U., Pastur, G.M. & Iverson, L.R.). Springer International Publishing, Cham, 1–10.

Guiterman, C.H., Gregg, R.M., Marshall, L.A.E., Beckmann, J.J., van Mantgem, P.J., Falk, D.A., et al. (2022). Vegetation type conversion in the US Southwest: frontline observations and management responses. Fire Ecology, 18, 6.

Guiterman, C.H., Margolis, E.Q., Baisan, C.H., Falk, D.A., Allen, C.D. & Swetnam, T.W. (2019). Spatiotemporal variability of human–fire interactions on the Navajo Nation. Ecosphere, 10, e02932.

Guyette, R.P., Muzika, R.M. & Dey, D.C. (2002). Dynamics of an anthropogenic fire regime. Ecosystems, 5, 472-486.

Hagedorn, B. & Flower, A. (2021). Conifer establishment and encroachment on subalpine meadows around Mt. Baker, WA, USA. Forests, 12, 1390.

Hagmann, R.K., Hessburg, P.F., Prichard, S.J., Povak, N.A., Brown, P.M., Fulé, P.Z., et al. (2021). Evidence for widespread changes in the structure, composition, and fire regimes of western North American forests. Ecological Applications, 31, 1–34.

Hämäläinen, P. (2022). Indigenous Continent: The Epic Contest for North America, 1st Edition. Liveright Publishing Company, NY.

Hamilton, H., Smyth, R.L., Young, B.E., Howard, T.G., Tracey, C., Breyer, S., et al. (2022). Increasing taxonomic diversity and spatial resolution clarifies opportunities for protecting US imperiled species. Ecological Applications, 32, e2534.

Hanberry, B. & Abrams, M. (2018). Recognizing loss of open forest ecosystems by tree densification and land use intensification in the Midwestern USA. Regional Environmental Change, 18, 1–10.

Hanberry, B.B., Abrams, M.D., Arthur, M.A. & Varner, J.M. (2020). Reviewing fire, climate, deer, and foundation species as drivers of historically open oak and pine forests and transition to closed forests. Frontiers in Forests and Global Change, 3.

Hanes, C.C., Wang, X., Jain, P., Parisien, M.-A., Little, J.M. & Flannigan, M.D. (2019). Fire-regime changes in Canada over the last half century. Canadian Journal of Forest Research, 49, 256–269.

Hankins, D. (2006). Pyrogeography in Riparian Ecosystems: An Indigenous Tool for Resource Management and Conservation. US Community Forestry Research Fellowships, College of Natural Resources, University of California Berkeley, Berkeley, CA.

Hankins, D.L. (2013). The effects of Indigenous prescribed fire on riparian vegetation in central California. Ecological Processes, 2, 24.

Hankins, D.L. (2015). Restoring Indigenous prescribed fires to California oak woodlands. In: Proceedings of the Seventh California Oak Symposium: Managing Oak Woodlands in a Dynamic World (Gen. Tech. Rep. No. PSW-GTR-251). U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Berkeley, CA, 123–129.

Hankins, D.L. (2021). Reading the Landscape for Fire. Bay Nature.

Hansen, E.M., Stone, J.K., Capitano, B.R., Rosso, P., Sutton, W., Winton, L., et al. (2000). Incidence and impact of Swiss needle cast in forest plantations of Douglas-fir in coastal Oregon. Plant Disease, 84, 773–778.

Harley, G.L., Heyerdahl, E.K., Johnston, J.D. & Olson, D.L. (2020). Riparian and adjacent upland forests burned synchronously during dry years in eastern Oregon (1650–1900 CE), USA. International Journal of Wildland Fire, 29, 602–610.

Hart-Fredeluces, G.M., Burnham, M., Vaughan, M.B., Hart, G., Hart, J.A., Martin, E.S., et al. (2022). Indigenous caretaking of beargrass and the social and ecological consequences of adaptations to maintain beargrass weaving practices. Ecology and Society, 27.

Hatton, T.J. & Williamson, J.G. (1992). International Migration and World Development: A Historical Perspective. Historical Working Paper Series, National Bureau of Economic Research.

Haugo, R.D., Kellogg, B.S., Cansler, C.A., Kolden, C.A., Kemp, K.B., Robertson, J.C., et al. (2019). The missing fire: quantifying human exclusion of wildfire in Pacific Northwest forests, USA. Ecosphere, 10, e02702.

Hayden, B. & Ryder, J.M. (1991). Prehistoric cultural collapse in the Lillooet area. American Antiquity, 56, 50–65.

Hayes, K. & Buma, B. (2021). Effects of short-interval disturbances continue to accumulate, overwhelming variability in local resilience. Ecosphere, 12, e03379.

Heart, M.Y.H.B. & DeBruyn, L.M. (1998). The American Indian holocaust: healing historical unresolved grief. American Indian and Alaska Native Mental Health Research, 8, 60–82.

Hebda, R.J. & Mathewes, R.W. (1984). Holocene history of cedar and Native Indian cultures of the North American Pacific Coast. Science, 225, 711–713.

Heinselman, M.L. (1973). Fire in the virgin forests of the Boundary Waters Canoe Area, Minnesota. Quaternary Research, 3, 329–382.

Helbig, M., Pappas, C. & Sonnentag, O. (2016). Permafrost thaw and wildfire: equally important drivers of boreal tree cover changes in the Taiga Plains, Canada. Geophysical Research Letters, 43, 1598–1606.

Hessburg, P.F. & Agee, J.K. (2003). An environmental narrative of Inland Northwest United States forests, 1800–2000. Forest Ecology and Management, 178, 23–59.

Hessburg, P.F., Miller, C.L., Parks, S.A., Povak, N.A., Taylor, A.H., Higuera, P.E., et al. (2019). Climate, environment, and disturbance history govern resilience of western North American forests. Frontiers in Ecology and Evolution, 7.

Hessburg, P.F., Prichard, S.J., Hagmann, R.K., Povak, N.A. & Lake, F.K. (2021). Wildfire and climate change adaptation of western North American forests: a case for intentional management. Ecological Applications, 31, e02432.

Hessburg, P.F., Spies, T.A., Perry, D.A., Skinner, C.N., Taylor, A.H., Brown, P.M., et al. (2016). Tamm Review: Management of mixed-severity fire regime forests in Oregon, Washington, and Northern California. Forest Ecology and Management, 366, 221–250.

Hicks, R. (1997). A resource at the crossroads: A history of the central hardwoods. In: Proceedings of the 11th Central Hardwood Forest Conference, Columbia, Missouri March 23-26, 1997. (GTR-NC-188). US Department of Agriculture, Forest Service, North Central Forest Experiment Station, St. Paul, MN, 1-22.

Higuera, P.E., Shuman, B.N. & Wolf, K.D. (2021). Rocky Mountain subalpine forests now burning more than any time in recent millennia. Proceedings of the National Academy of Sciences, 118, e2103135118.

Hoagland, S.J. (2017). Integrating traditional ecological knowledge with western science for optimal natural resource management.

IK: Other Ways of Knowing, 3, 1–15.

Hoffman, K.M., Christianson, A.C., Dickson-Hoyle, S., Copes-Gerbitz, K., Nikolakis, W., Diabo, D.A., et al. (2022). The right to burn: barriers and opportunities for Indigenous-led fire stewardship in Canada. FACETS, 7, 464–481.

Hoffman, K.M., Gavin, D.G., Lertzman, K.P., Smith, D.J. & Starzomski, B.M. (2016). 13,000 years of fire history derived from soil charcoal in a British Columbia coastal temperate rain forest. Ecosphere, 7, e01415.

Hoffman, K.M., Lertzman, K.P. & Starzomski, B.M. (2017). Ecological legacies of anthropogenic burning in a British Columbia coastal temperate rain forest. Journal of Biogeography, 44, 2903–2915.

Holmes, M.A., Whitacre, J.V., Bennion, L.D., Poteet, J. & Kuebbing, S.E. (2021). Land-use history and abiotic gradients drive abundance of non-native shrubs in Appalachian second-growth forests with histories of mining, agriculture, and logging. Forest Ecology and Management, 494, 119296.

Hubert, M.M., Schweitzer, J.A., Giam, X. & Papeş, M. (2023). Contrasting effects of urbanization and fire on understory plant communities in the natural and wildland–urban interface. Ecosphere, 14, e4520.

Hurteau, M.D., North, M.P., Koch, G.W. & Hungate, B.A. (2019). Managing for disturbance stabilizes forest carbon. Proceedings of the National Academy of Sciences, 116, 10193–10195.

Hutchinson, T.F., Stambaugh, M.C., Marschall, J.M. & Guyette, R.P. (2019). Historical fire in the Appalachian Plateau of Ohio and Kentucky, USA, from remnant yellow pines. Fire Ecology, 15, 1-12.

Jain, T.B., Abrahamson, I., Anderson, N., Hood, S., Hanberry, B., Kilkenny, F., et al. (2021). Effectiveness of fuel treatments at the landscape scale: state of understanding and key research gaps. JFSP Final Report 19-S-01-2. Join Fire Sciences Program, Boise, ID.

Jennings, L., Anderson, T., Martinez, A., Sterling, R., Chavez, D.D., Garba, I., et al. (2023). Applying the 'CARE Principles for Indigenous Data Governance' to ecology and biodiversity research. Nature Ecology and Evolution, 7, 1547–1551.

Jobidon, R., Bergeron, Y., Robitaille, A., Raulier, F., Gauthier, S., Imbeau, L., et al. (2015). A biophysical approach to delineate a northern limit to commercial forestry: the case of Quebec's boreal forest. Canadian Journal of Forest Research, 45, 515–528.

Johnson, N.K., Franklin, J.F. & Reeves, G.H. (2023). The Making of the Northwest Forest Plan: The Wild Science of Saving Old Growth Ecosystems. Oregon State University Press, Corvallis, OR.

Johnston, J.D., Schmidt, M.R., Merschel, A.G., Downing, W.M., Coughlan, M.R. & Lewis, D.G. (2023). Exceptional variability in historical fire regimes across a western Cascades landscape, Oregon, USA. Ecosphere, 14, e4735.

Johnstone, J.F., Allen, C.D., Franklin, J.F., Frelich, L.E., Harvey, B.J., Higuera, P.E., et al. (2016). Changing disturbance regimes, ecological memory, and forest resilience. Frontiers in Ecology and the Environment, 14, 369–378.

Jones, G.A. & Russell, W. (2015). Approximation of fire-return intervals with point samples in the southern range of the coast redwood forest, California, USA. Fire Ecology, 11, 80–94.

Jones, R.A. (2014). The role of Native American fire regimes in the maintenance of longleaf pine savanna. PhD Dissertation. University of Wyoming, Laramie, WY.

Joseph, L. & Turner, N.J. (2020). "The Old Foods Are the New Foods!": Erosion and revitalization of Indigenous food systems in Northwestern North America. Frontiers in Sustainable Food Systems, 4.

Kalies, E.L. & Yocom Kent, L.L. (2016). Tamm Review: Are fuel treatments effective at achieving ecological and social objectives? A systematic review. Forest Ecology and Management, 375, 84–95.

Kalisz, P.J. (1986). Soil properties of steep Appalachian old fields. Ecology 67, 1011-1023.

Kartesz, J.T. (2015). The Biota of North America Program (BONAP). North American Plant Atlas. Available at: http://bonap.net/napa.

Kasischke, E.S. & Turetsky, M.R. (2006). Recent changes in the fire regime across the North American boreal region—spatial and temporal patterns of burning across Canada and Alaska. Geophysical Research Letters, 33.

Kay, C.E. (2000). Native burning in western North America: implications for hardwood forest management. In: Proceedings of the Workshop on Fire, People, and the Central Hardwoods Landscape (Gen. Tech. Rep. No. NE-274). U.S. Department of Agriculture, Forest Service, Northeastern Research Station, Newton Square, PA.

Keeton, W.S. (2020). Eastern Old-growth Forests in an Era of Change. Northern Woodlands, Spring 2020.

Kellett, M.J., Maloof, J.E., Masino, S.A., Frelich, L.E., Faison, E.K., Brosi, S.L., et al. (2023). Forest-clearing to create early-successional habitats: questionable benefits, significant costs. Frontiers in Forests and Global Change, 5.

Kelly, R., Chipman, M.L., Higuera, P.E., Stefanova, I., Brubaker, L.B. & Hu, F.S. (2013). Recent burning of boreal forests exceeds fire regime limits of the past 10,000 years. Proceedings of the National Academy of Sciences, 110, 13055–13060.

Kimmerer, R. (2011). Restoration and reciprocity: the contributions of traditional ecological knowledge. In: Human Dimensions of Ecological Restoration: Integrating Science, Nature, and Culture, Society for Ecological Restoration (eds. Egan, D., Hjerpe, E.E. & Abrams, J.). Island Press/Center for Resource Economics, Washington, DC, 257–276.

Kimmerer, R.W. (2013). Braiding Sweetgrass: Indigenous Wisdom, Scientific Knowledge and the Teachings of Plants. Milkweed Editions.

Kimmerer, R.W. & Lake, F.K. (2001). The role of Indigenous burning in land management. Journal of Forestry, 99, 36–41.

Kipfmueller, K.F., Larson, E.R., Johnson, L.B. & Schneider, E.A. (2021). Human augmentation of historical red pine fire regimes in the Boundary Waters Canoe Area Wilderness. Ecosphere, 12, e03673.

Kirchmeier-Young, M.C., Gillett, N.P., Zwiers, F.W., Cannon, A.J. & Anslow, F.S. (2018). Attribution of the influence of human-induced climate change on an extreme fire season. Earth's Future, 7, 2–10.

Klimaszewski-Patterson, A., Dingemans, T., Morgan, C.T. & Mensing, S.A. (2024). Human influence on late Holocene fire history in a mixed-conifer forest, Sierra National Forest, California. Fire Ecology, 20, 3.

Klimaszewski-Patterson, A. & Mensing, S.A. (2016). Multi-disciplinary approach to identifying Native American impacts on Late Holocene forest dynamics in the southern Sierra

Nevada range, California, USA. Anthropocene, 15, 37–48.
Klimaszewski-Patterson, A., Weisberg, P.J., Mensing, S.A. & Scheller, R.M. (2018). Using paleo landscape modeling to investigate the impact of Native American–set fires on pre-Columbian forests in the southern Sierra Nevada, California, USA. Annals of the American Association of Geographers, 108, 1635–1654.
Knapp, E.E., Skinner, C.N., North, M.P. & Estes, B.L. (2013). Long-term overstory and understory change following logging and fire exclusion in a Sierra Nevada mixed-conifer forest. Forest Ecology and Management, 310, 903–914.
Knight, C.A., Anderson, L., Bunting, M.J., Champagne, M., Clayburn, R.M., Crawford, J.N., et al. (2022). Land management explains major trends in forest structure and composition over the last millennium in California's Klamath Mountains. Proceedings of the National Academy of Sciences, 119, e2116264119.
Kobziar, L.N., Godwin, D., Taylor, L. & Watts, A.C. (2015). Perspectives on trends, effectiveness, and impediments to prescribed burning in the southern U.S. Forests, 6, 561–580.
Krawchuk, M.A., Haire, S.L., Coop, J., Parisien, M.-A., Whitman, E., Chong, G., et al. (2016). Topographic and fire weather controls of fire refugia in forested ecosystems of northwestern North America. Ecosphere, 7, e01632.
Kreye, J.K., Varner, J.M., Hiers, J.K. & Mola, J. (2013). Toward a mechanism for eastern North American forest mesophication: differential litter drying across 17 species. Ecological Applications, 23, 1976–1986.
Kubian, R. (2013). Characterizing the mixed-severity fire regime of the Kootenay Valley, Kootenay National Park. MS Thesis, University of Victoria, British Columbia, Canada.
Kuhman, T.R., Pearson, S.M. & Turner, M.G. (2011). Agricultural land-use history increases non-native plant invasion in a southern Appalachian forest a century after abandonment. Canadian Journal of Forest Research, 41, 920-929.
Kulman, H.M., Hodson, A.C. & Duncan, D.P. (1963). Distribution and effects of jack pine budworm defoliation. Forest Science, 9, 146–157.
Kupfer, J.A., Terando, A.J., Gao, P., Teske, C. & Hiers, J.K. (2020). Climate change projected to reduce prescribed burning opportunities in the south-eastern United States. International Journal of Wildland Fire, 29, 764–778.
Kutenai Language Task Force. (1989). Available at: http://fwrconline.csktnrd.org/Fire/FireOnTheLand/History/TraditionalCulture/. Last accessed 23 February 2024.
Lafon, C.W., Naito, A.T., Grissino-Mayer, H.D., Horn, S.P. & Waldrop, T.A. (2017). Fire history of the Appalachian region: a review and synthesis. (GTR-SRS-219). US Department of Agriculture, Forest Service, Southern Research Station, Asheville, NC.
Lake, F., Parrotta, J., Giardina, C., Hunt-Davidson, I. & Uprety, Y. (2018). Integration of traditional and western knowledge in forest landscape restoration. In: Forest Landscape Restoration: Integrated approaches to support effective implementation, Routledge, 198–226.
Lake, F.K. & Christianson, A.C. (2019). Indigenous fire stewardship. In: Encyclopedia of Wildfires and Wildland-Urban Interface (WUI) Fires (ed. Manzello, S.L.). Springer International Publishing, Cham, 1–9.
Lake, F.K., Wright, V., Morgan, P., McFadzen, M., McWethy, D. & Stevens-Rumann, C. (2017). Returning fire to the land: celebrating traditional knowledge and fire. Journal of Forestry, 115, 343–353.
Landers, J.L., Van Lear, D.H. & Boyer, W.D. (1995). The longleaf pine forests of the southeast: requiem or renaissance? Journal of Forestry, 93.
Langton, M. (2004). Honour Among Nations?: Treaties and Agreements with Indigenous People. Melbourne University Publishing.
Larson, A.J., Jeronimo, S.M.A., Hessburg, P.F., Lutz, J.A., Povak, N.A., Cansler, C.A., et al. (2022). Tamm Review: Ecological principles to guide post-fire forest landscape management in the Inland Pacific and Northern Rocky Mountain regions. Forest Ecology and Management, 504, 119680.
Larson, G. & Schaetzl, R. (2001). Origin and evolution of the Great Lakes. Journal of Great Lakes Research, 27, 518–546.
Lasher-Trapp, S., Orendorf, S.A. & Trapp, R.J. (2023). Investigating a derecho in a future warmer climate. Bulletin of the American Meteorological Society, 104, e1831–e1852.
Lawal, S., Costanza, J., Koch, F.H. & Scheller, R.M. In press. Modeling the impacts of hot Drought on Forests in Texas. Frontiers in Forests and Global Change.
Leach, M.K. & Givnish, T.J. (1996). Ecological determinants of species loss in remnant prairies. Science, 273, 1555–1558.
LeCompte-Mastenbrook, J.K. (2015). Restoring Coast Salish foods and landscapes: a more-than-human politics of place, history and becoming. PhD Dissertation, University of Washington, Seattle, WA.
Lepofsky, D., Hallett, D., Washbrook, K., McHalsie, A., Lertzman, K., Mathewes, R., et al. (2005). Documenting precontact plant management on the Northwest Coast: an example of prescribed burning in the central and upper Fraser Valley, British Columbia. In: Keeping It Living: Traditions of Plant Use and Cultivation on the Northwest Coast of North America. University of Washington Press, Seattle, WA, 218–239.
Lepofsky, D. & Lertzman, K. (2008). Documenting ancient plant management in the northwest of North America. Botany, 86, 129–145.
Lertzman, K. (2009). The paradigm of management, management systems, and resource stewardship. Journal of Ethnobiology, 29, 339–358.
Leshy, J.D. (2022). Our Common Ground: A History of America's Public Lands. Yale University Press.
Lewis, H.T. (1973). Patterns of Indian Burning in California: Ecology and Ethnohistory. Ballena Press.
Lewis, H.T. & Ferguson, T.A. (1988). Yards, corridors, and mosaics: how to burn a boreal forest. Human Ecology, 16, 57–77.
Li, D. & Waller, D. (2015). Drivers of observed biotic homogenization in pine barrens of central Wisconsin. Ecology, 96, 1030–1041.
Li, S., Wang, G., Zhu, C., Lu, J., Ullah, W., Hagan, D.F.T., et al. (2022). Attribution of global evapotranspiration trends based on the Budyko framework. Hydrology and Earth System Sciences, 26, 3691–3707.
Lightfoot, K., Panich, L., Schneider, T. & Gonzalez, S. (2013). European colonialism and the Anthropocene: a view from the pacific coast of North America. Anthropocene, 4, 101–115.
Lindsay, M.M. & Bratton, S.P. (1979). Grassy balds of the Great Smoky Mountains: their history and flora in relation to potential management. Environmental Management, 3, 417-430.
Littell, J.S., McAfee, S.A. & Hayward, G.D. (2018). Alaska snowpack

response to climate change: statewide snowfall equivalent and snowpack water scenarios. Water, 10, 668.

Liu, N., Caldwell, P.V., Dobbs, G.R., Miniat, C.F., Bolstad, P.V., Nelson, S.A.C., et al. (2021). Forested lands dominate drinking water supply in the conterminous United States. Environmental Research Letters, 16, 084008.

Liu, N., Dobbs, G.R., Caldwell, P.V., Miniat, C.F., Sun, G., Duan, K., et al. (2022). Quantifying the role of National Forest System and other forested lands in providing surface drinking water supply for the conterminous US (Gen. Tech. Rep. No. WO-100). U.S. Department of Agriculture, Forest Service, Washington Office, Washington, DC.

Long, J.W., Anderson, M.K., Quinn-Davidson, L., Goode, R.W., Lake, F.K. & Skinner, C.N. (2016). Restoring California black oak ecosystems to promote tribal values and wildlife (Gen. Tech. Rep. No. PSW GTR-252). U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Albany, CA.

Long, J.W. & Davis, J. (2016). Erosion and restoration of two headwater wetlands following a severe wildfire. Ecological Restoration, 34, 317–332.

Long, J.W. & Lake, F.K. (2018). Escaping social-ecological traps through tribal stewardship on national forest lands in the Pacific Northwest, United States of America. Ecology and Society, 23, 10.

Long, J.W., Lake, F.K. & Goode, R.W. (2021). The importance of Indigenous cultural burning in forested regions of the Pacific West, USA. Forest Ecology and Management, 500, 119597.

Long, J.W., Walsh, D., Coppoletta, M., Tompkins, R.E., Meyer, M.D., Isbell, C., et al. (2023). Interventions to restore wildfire-altered forests in California (Gen. Tech. Rep. No. PSW-GTR-278). U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Albany, CA.

Loope, W.L. & Anderton, J.B. (1998). Human vs. lightning ignition of presettlement surface fires in coastal pine forests of the upper Great Lakes. The American Midland Naturalist, 140, 206–218.

Lorimer, C.G., Porter, D.J., Madej, M.A., Stuart, J.D., Veirs, S.D., Norman, S.P., et al. (2009). Presettlement and modern disturbance regimes in coast redwood forests: implications for the conservation of old-growth stands. Forest Ecology and Management, 258, 1038–1054.

Lorimer, C.G. & White, A.S. (2003). Scale and frequency of natural disturbances in the northeastern US: implications for early successional forest habitats and regional age distributions. Forest Ecology and Management, 185, 41–64.

Lovett, G.M., Weiss, M., Liebhold, A.M., Holmes, T.P., Leung, B., Lambert, K.F., et al. (2016). Nonnative forest insects and pathogens in the United States: impacts and policy options. Ecological Applications, 26, 1437–1455.

Lucash, M.S., Scheller, R.M., J. Gustafson, E. & R. Sturtevant, B. (2017). Spatial resilience of forested landscapes under climate change and management. Landscape Ecology, 32, 953–969.

Mack, C. & McClure, R. (2002). Vaccinium processing in the Washington Cascades. Journal of Ethnobiology, 22, 35–60.

Mackey, B., Lindenmayer, D., Norman, P., Taylor, C. & Gould, S. (2021). Are fire refugia less predictable due to climate change? Environmental Research Letters, 16, 114028.

Mah, S. (2000). Relationship between vital attributes of Ktunaxa plants and natural disturbance regimes in Southeastern British Columbia. University of British Columbia, Vancouver, British Columbia, Canada.

Maloney, P.E., Smith, T.F., Jensen, C.E., Innes, J., Rizzo, D.M. & North, M.P. (2008). Initial tree mortality and insect and pathogen response to fire and thinning restoration treatments in an old-growth mixed-conifer forest of the Sierra Nevada, California. Canadian Journal of Forest Research, 38, 3011–3020.

Mann, D.H., Rupp, T.S., Olson, M.A. & Duffy, P.A. (2012). Is Alaska's boreal forest now crossing a major ecological threshold? Arctic, Antarctic, and Alpine Research, 44, 319–331.

Margolis, E.Q., Guiterman, C.H., Chavardès, R.D., Coop, J.D., Copes-Gerbitz, K., Dawe, D.A., et al. (2022). The North American tree-ring fire-scar network. Ecosphere, 13, e4159.

Marks-Block, T., Lake, F.K., Bliege Bird, R. & Curran, L.M. (2021). Revitalized Karuk and Yurok cultural burning to enhance California hazelnut for basketweaving in northwestern California, USA. Fire Ecology, 17, 6.

Marlon, J.R., Bartlein, P.J., Gavin, D.G., Long, C.J., Anderson, R.S., Briles, C.E., et al. (2012). Long-term perspective on wildfires in the western USA. Proceedings of the National Academy of Sciences, 109, E535–E543.

Marschall, J.M., Stambaugh, M.C., Abadir, E.R., Dey, D.C., Brose, P.H., Bearer, S.L., et al. (2022). Pre-Columbian red pine (Pinus resinosa Ait.) fire regimes of north-central Pennsylvania, USA. Fire Ecology, 18, 11.

Martinez, D.J., Seraphin, B., Marks-Block, T., Nelson, P. & Vinyeta, K. (2023). Indigenous fire futures: anticolonial approaches to shifting fire relations in California. Environment and Society, 14, 142–161.

McCaffrey, D. & Hopkinson, C. (2020). Repeat oblique photography shows terrain and fire-exposure controls on century-scale canopy cover change in the alpine treeline ecotone. Remote Sensing, 12, 1569.

McCauley, L.A., Bradford, J.B., Robles, M.D., Shriver, R.K., Woolley, T.J. & Andrews, C.A. (2022). Landscape-scale forest restoration decreases vulnerability to drought mortality under climate change in southwest USA ponderosa forest. Forest Ecology and Management, 509, 120088.

McClure, M.M., Carlson, S.M., Beechie, T.J., Pess, G.R., Jorgensen, J.C., Sogard, S.M., et al. (2008). Evolutionary consequences of habitat loss for Pacific anadromous salmonids. Evolutionary Applications, 1, 300–318.

McCullough, D.G., Werner, R.A. & Neumann, D. (1998). Fire and insects in northern and boreal forest ecosystems of North America. Annual Review of Entomology, 43, 107–127.

McDonnell, M.A. (2015). Masters of Empire: Great Lakes Indians and the Making of America. Farrar, Straus and Giroux.

McEwan, R.W., Dyer, J.M. & Pederson, N. (2011). Multiple interacting ecosystem drivers: toward an encompassing hypothesis of oak forest dynamics across eastern North America. Ecography, 34, 244-256.

McKinley, D.C., Ryan, M.G., Birdsey, R.A., Giardina, C.P., Harmon, M.E., Heath, L.S., et al. (2011). A synthesis of current knowledge on forests and carbon storage in the United States. Ecological Applications, 21, 1902–1924.

Meigs, G.W., Case, M.J., Churchill, D.J., Hersey, C.M., Jeronimo, S.M.A. & Smith, L.A.C. (2023). Drought, wildfire and forest transformation: characterizing trailing edge forests in the eastern Cascade Range, Washington, USA. Forestry, 96, 340–354.

Melvin, M.A. (2020). 2020 National Prescribed Fire Use Report

(Technical Bulletin No. 04–20). Coalition of Prescribed Fire Councils, Inc. and National Association of State Foresters.

Merschel, A.G. (2021). Historical forest succession and disturbance dynamics in Coastal Douglas-fir forests in the southern western Cascades of Oregon. PhD Dissertation. Oregon State University, Corvallis, OR.

Merschel, A.G., Beedlow, P.A., Shaw, D.C., Woodruff, D.R., Lee, E.H., Cline, S.P., et al. (2021). An ecological perspective on living with fire in ponderosa pine forests of Oregon and Washington: resistance, gone but not forgotten. Trees, Forests and People, 4, 100074.

Michaelian, M., Hogg, E.H., Hall, R.J. & Arsenault, E. (2011). Massive mortality of aspen following severe drought along the southern edge of the Canadian boreal forest. Global Change Biology, 17, 2084–2094.

Miller, A.M. & Davidson-Hunt, I. (2010). Fire, agency and scale in the creation of Aboriginal cultural landscapes. Human Ecology, 38, 401–414.

Miller, A.M., Davidson-Hunt, I.J. & Peters, P. (2010). Talking about fire: Pikangikum First Nation elders guiding fire management. Canadian Journal of Forest Research. 40, 2290–2301.

Minore, D. (1972). The Wild Huckleberries of Oregon and Washington: A Dwindling Resource. Pacific Northwest Forest and Range Experiment Station, U.S. Department of Agriculture, Forest Service, Portland, OR.

Mitchell, S.J. (2013). Wind as a natural disturbance agent in forests: a synthesis. Forestry: An International Journal of Forest Research, 86, 147–157.

Mockta, T.K., Fulé, P.Z., Sánchez Meador, A., Padilla, T. & Kim, Y.-S. (2018). Sustainability of culturally important teepee poles on Mescalero Apache Tribal Lands: characteristics and climate change effects. Forest Ecology and Management, 430, 250–258.

Morrison, P.H. & Swanson, F.J. (1990). Fire history and pattern in a Cascade Range landscape. (Gen. Tech. Rep. No. PNW-GTR-254). U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR.

Moulinier, J., Lorenzetti, F. & Bergeron, Y. (2013). Effects of a forest tent caterpillar outbreak on the dynamics of mixedwood boreal forests of eastern Canada. Écoscience, 20, 182–193.

Muzika, R.M., Guyette, R.P., Stambaugh, M.C. & Marschall, J.M. (2015). Fire, drought, and humans in a heterogeneous Lake Superior landscape. Journal of Sustainable Forestry, 34, 49–70.

Myers, R.L. & Ewel, J.J. (1990). Scrub and high pine. In: Ecosystems of Florida. University of Central Florida Press, Orlando, FL.

Navarro, L., Morin, H., Bergeron, Y. & Girona, M.M. (2018). Changes in spatiotemporal patterns of 20th century spruce budworm outbreaks in eastern Canadian boreal forests. Frontiers in Plant Science, 9.

Nelson, J.W. (2019). The ecology of travel on the Great Lakes frontier: native knowledge, European dependence, and the environmental specifics of contact. Michigan Historical Review, 45, 1–26.

Nelson, M.P. & Callicott, J.B. (2008). The Wilderness Debate Rages On: Continuing the Great New Wilderness Debate. University of Georgia Press, Athens, GA.

Norgaard, K.M. (2019). Salmon and acorns feed our people. Rutgers University Press.

North, M.P., Schwartz, M.W., Collins, B.M. & Keane, J.J. (2017). Current and projected condition of mid-elevation Sierra Nevada forests. In: The California Spotted Owl: A Technical Assessment of Its Current Status (Gen. Tech. Rep. No. PSW-GTR-254). U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Albany, CA.

North, M.P., Stephens, S.L., Collins, B.M., Agee, J.K., Aplet, G., Franklin, J.F., et al. (2015). Reform forest fire management. Science, 349, 1280–1281.

North, M.P., Tompkins, R.E., Bernal, A.A., Collins, B.M., Stephens, S.L. & York, R.A. (2022). Operational resilience in western US frequent-fire forests. Forest Ecology and Management, 507, 120004.

Nowacki, G.J. & Abrams, M.D. (2008). The demise of fire and "mesophication" of forests in the eastern United States. BioScience, 58, 123–138.

O'Brien, S. (1984). The Medicine Line: A border dividing tribal sovereignty, economies and families. Fordham Law Review, 53, 315.

Oak, S.W., Spetich, M.A. and Morin, R.S. 2016. Oak decline in central hardwood forests: frequency, spatial extent, and scale. In: Greenberg, Cathryn H.; Collins, Beverly S. (eds.) Natural disturbances and historic range of variation: Type, frequency, severity, and post-disturbance structure in central hardwood forests USA. Managing Forest Ecosystems, 2015, Vol. 32, 49-71.

Obu, J., Westermann, S., Bartsch, A., Berdnikov, N., Christiansen, H.H., Dashtseren, A., et al. (2019). Northern Hemisphere permafrost map based on TTOP modelling for 2000–2016 at 1 km2 scale. Earth-Science Reviews, 193, 299–316.

Olson, S.D. (1996). The historical occurrence of fire in the central hardwoods, with emphasis on south central Indiana. Natural Areas Journal, 16, 248-256.

Omernik, J.M. & Griffith, G.E. (2014). Ecoregions of the conterminous United States: evolution of a hierarchical spatial framework. Environmental Management, 54, 1249–1266.

Oris, F., Asselin, H., Finsinger, W., Hély, C., Blarquez, O., Ferland, M.-E., et al. (2014). Long-term fire history in northern Quebec: implications for the northern limit of commercial forests. Journal of Applied Ecology, 51, 675–683.

Oswald, W.W., Foster, D.R., Shuman, B.N., Chilton, E.S., Doucette, D.L. & Duranleau, D.L. (2020a). Conservation implications of limited Native American impacts in pre-contact New England. Nature Sustainability, 3, 241–246.

Oswald, W.W., Foster, D.R., Shuman, B.N., Chilton, E.S., Doucette, D.L. & Duranleau, D.L. (2020b). W. W. Oswald et al. reply. Nature Sustainability, 3, 900–903.

Oswalt, C.M., Kush, J., Barlow, R.J. & Gilbert, J.C. (2012). Spatial and temporal trends of the shortleaf pine resource in the eastern United States. In: Proceedings of the Shortleaf Pine Conference: East Meets West, Special Report No. 11, Alabama Agricultural Experiment Station, Auburn University, Auburn, AL, 33-37.

Ouarmim, S., Ali, A.A., Asselin, H., Hély, C. & Bergeron, Y. (2015). Evaluating the persistence of post-fire residual patches in the eastern Canadian boreal mixedwood forest. Boreas, 44, 230–239.

Parisien, M.-A., Barber, Q.E., Hirsch, K.G., Stockdale, C.A., Erni, S., Wang, X., et al. (2020). Fire deficit increases wildfire risk for many communities in the Canadian boreal forest. Nature Communications, 11, 2121.

Parks, S.A. & Abatzoglou, J.T. (2020). Warmer and drier fire seasons contribute to increases in area burned at high severity in western US forests from 1985 to 2017. Geophysical Research

Letters, 47, e2020GL089858.

Parks, S.A., Holsinger, L.M., Miller, C. & Nelson, C.R. (2015). Wildland fire as a self-regulating mechanism: the role of previous burns and weather in limiting fire progression. Ecological Applications, 25, 1478–1492.

Pastor, J. (2016). What Should a Clever Moose Eat? Natural History, Ecology, and The North Woods. Island Press, Washington, DC, 131–142.

Paulson, A.K., Sanders, S., Kirschbaum, J. & Waller, D.M. (2016). Post-settlement ecological changes in the forests of the Great Lakes National Parks. Ecosphere, 7, e01490.

Pawlikowski, N.C., Coppoletta, M., Knapp, E. & Taylor, A.H. (2019). Spatial dynamics of tree group and gap structure in an old-growth ponderosa pine-California black oak forest burned by repeated wildfires. Forest Ecology and Management, 434, 289–302.

Payette, S. (2007). Contrasted dynamics of northern Labrador tree lines caused by climate change and migrational lag. Ecology, 88, 770–780.

Payette, S., Fortin, M.-J. & Gamache, I. (2001). The subarctic forest–tundra: The structure of a biome in a changing climate: the shifting of local subarctic tree lines throughout the forest–tundra biome, which is linked to ecological processes at different spatiotemporal scales, will reflect future global changes in climate. BioScience, 51, 709–718.

Pellatt, M.G. & Gedalof, Z. (2014). Environmental change in Garry oak (Quercus garryana) ecosystems: the evolution of an eco-cultural landscape. Biodiversity and Conservation, 23, 2053–2067.

Pellegrini, A.F.A., Caprio, A.C., Georgiou, K., Finnegan, C., Hobbie, S.E., Hatten, J.A., et al. (2021). Low-intensity frequent fires in coniferous forests transform soil organic matter in ways that may offset ecosystem carbon losses. Global Change Biology, 27, 3810–3823.

Pelz, K.A., Hayward, G., Gray, A.N., Berryman, E.M., Woodall, C.W., Nathanson, A., et al. (2023). Quantifying old-growth forest of United States Forest Service public lands. Forest Ecology and Management, 549, 121437.

Perala, D.A. (1985). Using glyphosate herbicide in converting aspen to conifers (Res. Pap. No. NC-259). U.S. Dept. of Agriculture, Forest Service, North Central Forest Experiment Station, ST. Paul, MN.

Perry, D.A., Hessburg, P.F., Skinner, C.N., Spies, T.A., Stephens, S.L., Taylor, A.H., et al. (2011). The ecology of mixed severity fire regimes in Washington, Oregon, and Northern California. Forest Ecology and Management, 262, 703–717.

Peterson, G.D. (2002). Contagious disturbance, ecological memory, and the emergence of landscape pattern. Ecosystems, 5, 329–338.

Platt, W.J. (1999). Southeastern pine savannas. In: Savannas, Barrens, and Rock Outcrop Plant Communities of North America (eds. Anderson, R.C., Fralish, J.S. & Baskin, J.M.). Cambridge University Press, 23–51.

Platt, W.J., Evans, G.W. & Rathbun, S.L. (1988). The population dynamics of a long-lived conifer (Pinus palustris). The American Naturalist, 131, 491–525.

Polinko, A.D., Willis, J.L., Sharma, A. & Guldin, J.M. (2022). Stand-level structural characteristics dictate hurricane resistance and resilience more than silvicultural regime in longleaf pine woodlands. Forest Ecology and Management, 526, 120585.

Potter, K.M., Escanferla, M.E., Jetton, R.M. & Man, G. (2019). Important insect and disease threats to United States tree species and geographic patterns of their potential impacts. Forests, 10, 304.

Povak, N.A., Hessburg, P.F., Salter, R.B., Gray, R.W. & Prichard, S.J. (2023). System-level feedbacks of active fire regimes in large landscapes. Fire Ecology, 19, 45.

Prein, A.F. (2023). Thunderstorm straight line winds intensify with climate change. Nature Climate Change, 13, 1353–1359.

Prichard, S.J., Hessburg, P.F., Hagmann, R.K., Povak, N.A., Dobrowski, S.Z., Hurteau, M.D., et al. (2021). Adapting western North American forests to climate change and wildfires: 10 common questions. Ecological Applications, 31, e02433.

Prichard, S.J., Stevens-Rumann, C.S. & Hessburg, P.F. (2017). Tamm Review: Shifting global fire regimes: lessons from reburns and research needs. Forest Ecology and Management, 396, 217–233.

Pullen, R. (1996). Overview of the environment of native inhabitants of southwestern Oregon, late prehistoric era. Pullen Consulting.

Pureswaran, D.S., De Grandpré, L., Paré, D., Taylor, A., Barrette, M., Morin, H., et al. (2015). Climate-induced changes in host tree–insect phenology may drive ecological state-shift in boreal forests. Ecology, 96, 1480–1491.

Pyne, S.J. (1997). Fire in America: A Cultural History of Wildland and Rural Fire. University of Washington Press, Seattle, WA.

Pyne, S.J., Andrews, P.L. & Laven, R.D. (1996). Introduction to Wildland Fire, 2nd Edition. Wiley, New York.

Radeloff, V.C., Hammer, R.B., Stewart, S.I., Fried, J.S., Holcomb, S.S. & McKeefry, J.F. (2005). The wildland–urban interface in the United States. Ecological Applications, 15, 799-805.

Radeloff, V.C., Helmers, D.P., Kramer, H.A., Mockrin, M.H., Alexandre, P.M., Bar-Massada, A., et al. (2018). Rapid growth of the US wildland-urban interface raises wildfire risk. Proceedings of the National Academy of Sciences, 115, 3314–3319.

Rapp, J.M., Lutz, D.A., Huish, R.D., Dufour, B., Ahmed, S., Morelli, T.L., et al. (2019). Finding the sweet spot: shifting optimal climate for maple syrup production in North America. Forest Ecology and Management, 448, 187–197.

Redmond, M.D., Urza, A.K. & Weisberg, P.J. (2023). Managing for ecological resilience of pinyon–juniper ecosystems during an era of woodland contraction. Ecosphere, 14, e4505.

Reid, A.J. (2020). Fish–people–place: interweaving knowledges to elucidate pacific salmon fate. PhD Dissertation. Carleton University.

Reilly, M.J., Halofsky, J.E., Krawchuk, M.A., Donato, D.C., Hessburg, P.F., Johnston, J.D., et al. (2021). Fire ecology and management in Pacific Northwest forests. In: Fire Ecology and Management: Past, Present, and Future of US Forested Ecosystems, Managing Forest Ecosystems (eds. Greenberg, C.H. & Collins, B.). Springer International Publishing, Cham, 393–435.

Reilly, M.J., Norman, S.P., O'Brien, J.J. & Loudermilk, E.L. (2022). Drivers and ecological impacts of a wildfire outbreak in the southern Appalachian Mountains after decades of fire exclusion. Forest Ecology and Management, 524, 120500.

Reilly, M.J., Zuspan, A., Halofsky, J.S., Raymond, C., McEvoy, A., Dye, A.W., et al. (2022). Cascadia burning: The historic, but not historically unprecedented, 2020 wildfires in the Pacific Northwest, USA. Ecosphere, 13, e4070.

Reisen, F., Duran, S.M., Flannigan, M., Elliott, C. & Rideout, K.

(2015). Wildfire smoke and public health risk. International Journal of Wildland Fire, 24, 1029–1044.
Reisser, M., Purves, R.S., Schmidt, M.W.I. & Abiven, S. (2016). Pyrogenic carbon in soils: a literature-based inventory and a global estimation of its content in soil organic carbon and stocks. Frontiers in Earth Science, 4.
Rhemtulla, J.M., Mladenoff, D.J. & Clayton, M.K. (2009). Legacies of historical land use on regional forest composition and structure in Wisconsin, USA (mid-1800s–1930s–2000s). Ecological Applications, 19, 1061–1078.
Riley, K., Grenfell, I.C. & Finney, M.A. (2016). Mapping forest vegetation for the western United States using modified random forests imputation of FIA forest plots. Ecosphere. 7(10): e01472., 7, e01472.
Ritóková, G., Shaw, D.C., Filip, G., Kanaskie, A., Browning, J. & Norlander, D. (2016). Swiss needle cast in western Oregon Douglas-Fir plantations: 20- Year monitoring results. Forests, 7, 155.
Robbins, W.G. (1997). Landscapes of Promise: The Oregon Story, 1800-1940. Weyerhaeuser Environmental Books. University of Washington Press, Seattle, WA.
Robbins, Z.J., Loudermilk, E.L., Mozelewski, T.G., Jones, K. & Scheller, R.M. (2024). Fire regimes of the Southern Appalachians may radically shift under climate change. Fire Ecology, 20, 2.
Rogeau, M.-P., Barber, Q.E. & Parisien, M.-A. (2018). Effect of topography on persistent fire refugia of the Canadian Rocky Mountains. Forests, 9, 285.
Rogeau, M.-P., Parisien, M.-A. & Flannigan, M.D. (2016). Fire history sampling strategy of fire intervals associated with mixed- to full-severity fires in southern Alberta, Canada. Forest Science, 62, 613–622.
Rollins, M.G. (2009). LANDFIRE: a nationally consistent vegetation, wildland fire, and fuel assessment. International Journal of Wildland Fire, 18, 235–249.
Roos, C.I., Guiterman, C.H., Margolis, E.Q., Swetnam, T.W., Laluk, N.C., Thompson, K.F., et al. (2022). Indigenous fire management and cross-scale fire-climate relationships in the Southwest United States from 1500 to 1900 CE. Science Advances, 8, eabq3221.
Roos, C.I., Swetnam, T.W., Ferguson, T.J., Liebmann, M.J., Loehman, R.A., Welch, J.R., et al. (2021). Native American fire management at an ancient wildland–urban interface in the Southwest United States. Proceedings of the National Academy of Sciences, 118, e2018733118.
Rother, M.T., Huffman, J.M., Guiterman, C.H., Robertson, K.M. & Jones, N. (2020). A history of recurrent, low-severity fire without fire exclusion in southeastern pine savannas, USA. Forest Ecology and Management, 475, 118406.
Royama, T. (1984). Population dynamics of the spruce budworm Choristoneura fumiferana. Ecological Monographs, 54, 429–462.
Rustad, L., Campbell, J., Dukes, J.S., Huntington, T., Fallon Lambert, K., Mohan, J., et al. (2012). Changing climate, changing forests: the impacts of climate change on forests of the northeastern United States and eastern Canada (Gen. Tech. Rep. No. NRS-99). U.S. Department of Agriculture, Forest Service, Northern Research Station, Newton Square, PA.
Ryan, K.C., Knapp, E.E. & Varner, J.M. (2013). Prescribed fire in North American forests and woodlands: history, current practice, and challenges. Frontiers in Ecology and the Environment, 11, e15–e24.
Safford, H.D., Paulson, A.K., Steel, Z.L., Young, D.J.N. & Wayman, R.B. (2022). The 2020 California fire season: A year like no other, a return to the past or a harbinger of the future? Global Ecology and Biogeography, 31, 2005–2025.
Safford, H.D. & Stevens, J.T. (2017). Natural range of variation for yellow pine and mixed-conifer forests in the Sierra Nevada, southern Cascades, and Modoc and Inyo National Forests, California, USA. (Gen. Tech. Rep. No. PSW-GTR-256). U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Albany, CA.
Safranyik, L., Carroll, A.L., Régnière, J., Langor, D.W., Riel, W.G., Shore, T.L., et al. (2010). Potential for range expansion of mountain pine beetle into the boreal forest of North America. The Canadian Entomologist, 142, 415–442.
Sankey, T. & Tatum, J. (2022). Thinning increases forest resiliency during unprecedented drought. Nature Scientific Reports, 12, 9041.
Scheller, R.M., Van Tuyl, S., Clark, K., Hayden, N.G., Hom, J. & Mladenoff, D.J. (2008). Simulation of forest change in the New Jersey pine barrens under current and pre-colonial conditions. Forest Ecology and Management, 255, 1489–1500.
Scheller, R.M., Van Tuyl, S., Clark, K.L., Hom, J. & La Puma, I. (2011). Carbon sequestration in the New Jersey pine barrens under different scenarios of fire management. Ecosystems, 14, 987-1004.
Schenck, W.E. & Gifford, E.W. (1952). Archaeological sites on opposite shores of the Gulf of California. American Antiquity, 17, 265–265.
Schollaert, C.L., Jung, J., Wilkins, J., Alvarado, E., Baumgartner, J., Brun, J., et al. (2023). Quantifying the smoke-related public health trade-offs of forest management. Nature Sustainability, 1–10.
Scholten, R.C., Jandt, R., Miller, E.A., Rogers, B.M. & Veraverbeke, S. (2021). Overwintering fires in boreal forests. Nature, 593, 399–404.
Schulte, L.A., Mladenoff, D.J., Crow, T.R., Merrick, L.C. & Cleland, D.T. (2007). Homogenization of northern U.S. Great Lakes forests due to land use. Landscape Ecology, 22, 1089–1103.
Schultz, C.A., McCaffrey, S.M. & Huber-Stearns, H.R. (2019). Policy barriers and opportunities for prescribed fire application in the western United States. International Journal of Wildland Fire, 28, 874–884.
Schwarz, A.G. & Wein, R.W. (1997). Threatened dry grasslands in the continental boreal forests of Wood Buffalo National Park. Canadian Journal of Botany, 75, 1363–1370.
Scott, L.M. (1928). Indian diseases as aids to Pacific Northwest settlement. Oregon Historical Quarterly, 29, 144–161.
Searle, E.B. & Chen, H.Y.H. (2017a). Climate change-associated trends in biomass dynamics are consistent across soil drainage classes in western boreal forests of Canada. Forest Ecosystems, 4, 18.
Searle, E.B. & Chen, H.Y.H. (2017b). Persistent and pervasive compositional shifts of western boreal forest plots in Canada. Global Change Biology, 23, 857–866.
Shebitz, D.J., Reichard, S.H. & Dunwiddie, P.W. (2009). Ecological and cultural significance of burning beargrass habitat on the Olympic Peninsula, Washington. Ecological Restoration, 27, 306–319.

Shores, C.R., Mikle, N. & Graves, T.A. (2019). Mapping a keystone shrub species, huckleberry (Vaccinium membranaceum), using seasonal colour change in the Rocky Mountains. International Journal of Remote Sensing, 40, 5695–5715.

Sieg, C.H., Linn, R.R., Pimont, F., Hoffman, C.M., McMillin, J.D., Winterkamp, J., et al. (2017). Fires following bark beetles: factors controlling severity and disturbance interactions in ponderosa pine. Fire Ecology, 13, 1–23.

Sierra-Hernández, M.R., Beaudon, E., Porter, S.E., Mosley-Thompson, E. & Thompson, L.G. (2022). Increased fire activity in Alaska since the 1980s: evidence from an ice core-derived black carbon record. Journal of Geophysical Research: Atmospheres, 127, e2021JD035668.

Sillett, S.C. & Van Pelt, R. (2007). Trunk reiteration promotes epiphytes and water storage in an old-growth redwood forest canopy. Ecological Monographs, 77, 335–359.

Slaton, M.R., Holmquist, J.G., Meyer, M., Andrews, R. & Beidl, J. (2019). Traditional Ecological Knowledge used in forest restoration benefits natural and cultural resources: the intersection between pandora moths, Jeffrey pine, people, and fire. Natural Areas Journal, 39, 461–471.

Sloan, K. & Hostler, J. (2014). Utilizing Yurok Traditional Ecological Knowledge to inform climate change priorities. The North Pacific Landscape Conservation Cooperative, US Fish and Wildlife Service, Klamath, CA.

Smith, J.A., O'Donnell, K., Mount, L.L., Shin, K., Peacock, K., Trulock, A., et al. (2011). A novel fusarium species causes a canker disease of the critically endangered conifer, Torreya taxifolia. Plant Disease, 95, 633–639.

Smithwick, E.A.H., Caldwell, C., Klippel, A., Scheller, R.M., Tuana, N., Bird, R.B., et al. (2019). Learning about forest futures under climate change through transdisciplinary collaboration across traditional and western knowledge systems. In: Collaboration Across Boundaries for Social-Ecological Systems Science: Experiences Around the World (ed. Perz, S.G.). Springer International Publishing, Cham, 153–184.

Sork, V.L., Davis, F.W., Westfall, R., Flint, A., Ikegami, M., Wang, H., et al. (2010). Gene movement and genetic association with regional climate gradients in California valley oak (Quercus lobata Née) in the face of climate change. Molecular Ecology, 19, 3806–3823.

Soulard, C.E., Walker, J.J. & Griffith, G.E. (2017). Forest harvest patterns on private lands in the cascade mountains, Washington, USA. Forests, 8, 383.

Souther, S., Lyndon, N. & Randall, D. (2021). Insights into the restoration and sustainable management of Emory oak: a southwestern cultural keystone species. Forest Ecology and Management, 483, 118900.

Spetich, M.A., Perry, R.W., Harper, C.A. & Clark, S.L. (2011). Fire in eastern hardwood forests through 14,000 years. In: Greenberg, C.H., Collins, B.S., & Thompson, F.R. III (eds.). Sustaining young forest communities: ecology and management of early successional habitats in the Central Hardwood Region, USA., Managing Forest Ecosystems, 21, 41-58.

Spies, T.A., Long, J.W., Charnley, S., Hessburg, P.F., Marcot, B.G., Reeves, G.H., et al. (2019). Twenty-five years of the Northwest Forest Plan: what have we learned? Frontiers in Ecology and the Environment, 17, 511–520.

Spies, T.A., Stine, P.A., Gravenmier, R.A., Long, J.W. & Reilly, M.J. (2018). Synthesis of science to inform land management within the Northwest forest plan area (Gen. Tech. Rep. No. PNW-GTR-966). U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR.

Spring, A., Skinner, K., Simba, M., Nelson, E., Baltzer, J., Swanson, H., et al. (2019). Taking care of the land: An interdisciplinary approach to community-based food systems assessment in Kakisa, Northwest Territories, Canada. In: Sustainable Food System Assessment. Routledge, p. 24.

Sprugel, D.G. (1991). Disturbance, equilibrium, and environmental variability: What is 'natural' vegetation in a changing environment? Biological Conservation, 58, 1–18.

Stambaugh, M.C., Guyette, R.P. & Marschall, J. (2013). Fire history in the Cherokee Nation of Oklahoma. Human Ecology, 41, 749–758.

Stambaugh, M.C., Marschall, J.M. & Abadir, E.R. (2020). Revealing historical fire regimes of the Cumberland Plateau, USA, through remnant fire-scarred shortleaf pines (Pinus echinata Mill.). Fire Ecology, 16, 24.

Stambaugh, M.C., Marschall, J.M., Abadir, E.R., Jones, B.C., Brose, P.H., Dey, D.C., et al. (2018). Wave of fire: an anthropogenic signal in historical fire regimes across central Pennsylvania, USA. Ecosphere, 9, e02222.

Stambaugh, M.C., Marschall, J.M. & Guyette, R.P. (2014). Linking fire history to successional changes of xeric oak woodlands. Forest Ecology and Management, 320, 83–95.

Stambaugh, M.C., Varner, J.M. & Jackson, S.T. (2017). Biogeography: an interweave of climate, fire, and humans. In: Ecological Restoration and Management of Longleaf Pine Forests. CRC Press.

Stan, A.B., Fulé, P.Z. & Hunter Jr., M. (2022). Reduced forest vulnerability due to management on the Hualapai Nation. Trees, Forests and People, 10, 100325.

Stedman, R.C., Parkins, J.R. & Beckley, T.M. (2005). Forest dependence and community well-being in rural Canada: variation by forest sector and region. Canadian Journal of Forest Research, 35, 215–220.

Steel, Z.L., Foster, D., Coppoletta, M., Lydersen, J.M., Stephens, S.L., Paudel, A., et al. (2021). Ecological resilience and vegetation transition in the face of two successive large wildfires. Journal of Ecology, 109, 3340–3355.

Steel, Z.L., Koontz, M.J. & Safford, H.D. (2018). The changing landscape of wildfire: burn pattern trends and implications for California's yellow pine and mixed conifer forests. Landscape Ecology, 33, 1159–1176.

Steel, Z.L., Safford, H.D. & Viers, J.H. (2015). The fire frequency-severity relationship and the legacy of fire suppression in California forests. Ecosphere, 6, 8.

Stephens, S.L., Bernal, A.A., Collins, B.M., Finney, M.A., Lautenberger, C. & Saah, D. (2022). Mass fire behavior created by extensive tree mortality and high tree density not predicted by operational fire behavior models in the southern Sierra Nevada. Forest Ecology and Management, 518, 120258.

Stephens, S.L., Collins, B.M., Fettig, C.J., Finney, M.A., Hoffman, C.M., Knapp, E.E., et al. (2018). Drought, tree mortality, and wildfire in forests adapted to frequent fire. BioScience, 68, 77–88.

Stephens, S.L. & Fry, D.L. (2005). Fire history in coast redwood stands in the northeastern Santa Cruz Mountains, California. Fire Ecology, 1, 2–19.

Stephens, S.L., Kobziar, L.N., Collins, B.M., Davis, R., Fulé, P.Z., Gaines, W., et al. (2019). Is fire "for the birds"? How two rare species influence fire management across the US. Frontiers in Ecology and the Environment, 17, 391–399.
Stephens, S.L., Lydersen, J.M., Collins, B.M., Fry, D.L. & Meyer, M.D. (2015). Historical and current landscape-scale ponderosa pine and mixed conifer forest structure in the Southern Sierra Nevada. Ecosphere, 6, art79.
Stephens, S.L., Westerling, A.L., Hurteau, M.D., Peery, M.Z., Schultz, C.A. & Thompson, S. (2020). Fire and climate change: conserving seasonally dry forests is still possible. Frontiers in Ecology and the Environment, 18, 354–360.
Stevens, J.T., Collins, B.M., Miller, J.D., North, M.P. & Stephens, S.L. (2017). Changing spatial patterns of stand-replacing fire in California conifer forests. Forest Ecology and Management, 406, 28–36.
Stevens-Rumann, C.S., Kemp, K.B., Higuera, P.E., Harvey, B.J., Rother, M.T., Donato, D.C., et al. (2018). Evidence for declining forest resilience to wildfires under climate change. Ecology Letters, 21, 243–252.
Stevens-Rumann, C.S. & Morgan, P. (2019). Tree regeneration following wildfires in the western US: a review. Fire Ecology, 15, 15.
Stevens-Rumann, C.S., Prichard, S.J., Whitman, E., Parisien, M.-A. & Meddens, A.J.H. (2022). Considering regeneration failure in the context of changing climate and disturbance regimes in western North America. Canadian Journal of Forest Research, 52, 1281–1302.
Stockdale, C.A., Macdonald, S.E. & Higgs, E. (2019a). Forest closure and encroachment at the grassland interface: a century-scale analysis using oblique repeat photography. Ecosphere, 10, e02774.
Stockdale, C.A., McLoughlin, N., Flannigan, M. & Macdonald, S.E. (2019b). Could restoration of a landscape to a pre-European historical vegetation condition reduce burn probability? Ecosphere, 10, e02584.
Storm, L. & Shebitz, D. (2006). Evaluating the purpose, extent, and ecological restoration applications of Indigenous burning practices in southwestern Washington. Ecological Restoration, 24, 256–268.
Stralberg, D., Arseneault, D., Baltzer, J.L., Barber, Q.E., Bayne, E.M., Boulanger, Y., et al. (2020). Climate-change refugia in boreal North America: what, where, and for how long? Frontiers in Ecology and the Environment, 18, 261–270.
Susaeta, A., Fill, J., Crandall, R. & Varner, J.M. (2022). Hidden costs of fire exclusion in longleaf pine forests linked to duff and carbon management. Journal of Forestry, 120, 504–512.
Sutton, R.F. (1978). Glyphosate herbicide: an assessment of forestry potential. The Forestry Chronicle, 54, 24–28.
Swetnam, T.W., Allen, C.D. & Betancourt, J.L. (1999). Applied historical ecology: using the past to manage for the future. Ecological Applications, 9, 1189–1206.
Swetnam, T.W. & Brown, P.M. (1992). Oldest known conifers in the southwestern United States: temporal and spatial patterns of maximum age. In: Old Growth Forests in the Southwest and Rocky Mountain Regions (Gen. Tech. Rep. No. RM-GTR-213). U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Ft. Collins, CO.
Swetnam, T.W., Farella, J., Roos, C.I., Liebmann, M.J., Falk, D.A. & Allen, C.D. (2016). Multiscale perspectives of fire, climate and humans in western North America and the Jemez Mountains, USA. Philosophical Transactions of the Royal Society B: Biological Sciences, 371, 20150168.
Talty, M.J., Mott Lacroix, K., Aplet, G.H. & Belote, R.T. (2020). Conservation value of national forest roadless areas. Conservation Science and Practice, 2, e288.
Talucci, A.C., Meigs, G.W., Knudby, A. & Krawchuk, M.A. (2022). Fire severity and the legacy of mountain pine beetle outbreak: high-severity fire peaks with mixed live and dead vegetation. Environmental Research Letters, 17, 124010.
Tang, G. & Beckage, B. (2010). Projecting the distribution of forests in New England in response to climate change. Diversity and Distributions, 16, 144–158.
Taylor, A.H., Trouet, V., Skinner, C.N. & Stephens, S. (2016). Socioecological transitions trigger fire regime shifts and modulate fire–climate interactions in the Sierra Nevada, USA, 1600–2015 CE. Proceedings of the National Academy of Sciences, 113, 13684–13689.
Teitelbaum, S., Saganash, A. & Asselin, H. (2024). Forests, governance and the struggle for political autonomy: perspectives from the Cree First Nation of Waswanipi. In: INSTEAD: Indigenous Stewardship of Environment and Alternative Development. University of Toronto Press, Toronto.
Tepley, A.J., Swanson, F.J. & Spies, T.A. (2013). Fire-mediated pathways of stand development in Douglas-fir/western hemlock forests of the Pacific Northwest, USA. Ecology, 94, 1729–1743.
Thompson, M.P., Belval, E.J., Bayham, J., Calkin, D.E., Stonesifer, C.S. & Flores, D. (2023). Wildfire response: a system on the brink? Journal of Forestry, 121, 121–124.
Thornton, T.F. (2015). The ideology and practice of Pacific herring cultivation among the Tlingit and Haida. Human Ecology, 43, 213–223.
Timoney, K.P. & Mamet, S. (2019). No treeline advance over the last 50 years in subarctic western and central Canada and the problem of vegetation misclassification in remotely sensed data. Écoscience, 27, 93–106.
Timoney, K.P., Mamet, S.D., Cheng, R., Lee, P., Robinson, A.L., Downing, D., et al. (2019). Tree cover response to climate change in the forest-tundra of north-central Canada: fire-driven decline, not northward advance. Écoscience, 26, 133–148.
TNC. (2024). Osborne historic panoramas. The Nature Conservancy. Available at https://www.maps.tnc.org/osbornephotos/index.html. Last accessed 11 February 2024.
Todd, P.A. (2017). Yaaw (herring) & Gaax'w (herring eggs): the knowledge politics of a traditional Tlingit subsistence foodway in Sitka, Alaska. University of Cincinnati.
Trant, A.J. & Hermanutz, L. (2014). Advancing towards novel tree lines? A multispecies approach to recent tree line dynamics in subarctic alpine Labrador, northern Canada. Journal of Biogeography, 41, 1115–1125.
Treuer, D. (2019). The Heartbeat of Wounded Knee: Native America from 1890 to the Present. Penguin Publishing Group.
Turetsky, M.R., Benscoter, B., Page, S., Rein, G., van der Werf, G.R. & Watts, A. (2015). Global vulnerability of peatlands to fire and carbon loss. Nature Geosciences, 8, 11–14.
Turetsky, M.R., Mack, M.C., Hollingsworth, T.N. & Harden, J.W. (2010). The role of mosses in ecosystem succession and function in Alaska's boreal forest. Canadian Journal of Forest Research,

40, 1237–1264.
Turner, M.G., Braziunas, K.H., Hansen, W.D. & Harvey, B.J. (2019). Short-interval severe fire erodes the resilience of subalpine lodgepole pine forests. Proceedings of the National Academy of Sciences, 116, 11319–11328.
Turner, N., Thompson, L., Thompson, M. & York, A. (1990). Thompson ethnobotany: knowledge and uses of plants by the Thompson Indians. British Columbia Provincial Museum Memoir No. 25.
Turner, N.J. (1989). “All berries have relations”: mid-range folk plant groupings in Thompson and Lillooet interior Salish. Journal of Ethnobiology, 9, 69–100.
Turner, N.J. (1991). “Burning mountain sides for better crops:” aboriginal landscape burning in British Columbia. Archeology in Montana, 32, 57–73.
Turner, N.J., Deur, D. & Mellott, C.R. (2011). “Up on the mountain”: Ethnobotanical importance of montane sites in pacific coastal North America. Journal of Ethnobiology, 31, 4–43.
Turner, N.J., Lepofsky, D. & Deur, D. (2013). Plant management systems of British Columbia’s first peoples. BC Studies: The British Columbian Quarterly, 107–133.
Ulyshen, M., Urban-Mead, K.R., Dorey, J.B. & Rivers, J.W. (2023). Forests are critically important to global pollinator diversity and enhance pollination in adjacent crops. Biological Reviews, 98, 1118–1141.
USDA Forest Service. (1989). Chief Dale Robertson letter to regional foresters, station directors, and WO staff regarding national forest old-growth values and the generic definition and description of old-growth forests. U.S. Department of Agriculture, Forest Service.
USDA Forest Service. (2023). Mature and Old-Growth Forests: Definition, Identification, and Initial Inventory on Lands Managed by the Forest Service and Bureau of Land Management (2023). U.S. Department of Agriculture, Forest Service.
USFWS. (2017). Federal and State Endangered and Threatened Species Expenditures. U.S. Fish & Wildlife Service.
USGCRP. (2023). Fifth National Climate Assessment. U.S. Global Change Research Program, Washington, DC.
Vaillant, N.M. & Stephens, S.L. (2009). Fire history of a lower elevation Jeffrey pine-mixed conifer forest in the eastern Sierra Nevada, California, USA. Fire Ecology, 5, 4–19.
Van Lear, D.H., Carroll, W.D., Kapeluck, P.R. & Johnson, R. (2005). History and restoration of the longleaf pine-grassland ecosystem: implications for species at risk. Forest Ecology and Management, 211, 150–165.
Van Lear, D.H. & Waldrop, T.A. (1989). History, uses, and effects of fire in the Appalachians. (GTR-SRS-54). US Department of Agriculture, Forest Service, Southeastern Forest Experiment Station, Asheville, NC.
van Wagtendonk, J.W. (1979). Wilderness fire management in Yosemite National Park. In: Earthcare: Global Protection Of Natural Areas. Routledge.
Vander Yacht, A.L., Keyser, P.D., Barrioz, S.A., Kwit, C., Stambaugh, M.C., Clatterbuck, W.K., et al. (2019). Reversing mesophication effects on understory woody vegetation in mid-southern oak forests. Forest Science, 65, 289–303.
Varner, J.M., Gordon, D.R., Putz, F.E. & Hiers, J.K. (2005). Restoring fire to long-unburned Pinus palustris ecosystems: novel fire effects and consequences for long-unburned ecosystems. Restoration Ecology, 13, 536–544.
Varner, J.M. & Kush, J.S. (2004). Remnant old-growth longleaf pine (Pinus palustris Mill.) savannas and forests of the Southeastern USA: status and threats. Natural Areas Journal, 24, 141–149.
Varner, J.M. (2018). Encroachment and persistence of trees in southeastern grasslands. In: Southeastern Grasslands: Biodiversity, Ecology, and Management. The University of Alabama Press, Tuscaloosa, AL, 183–191.
Varner, J.M., Hiers, J.K., Ottmar, R.D., Gordon, D.R., Putz, F.E. & Wade, D.D. (2007). Overstory tree mortality resulting from reintroducing fire to long-unburned longleaf pine forests: the importance of duff moisture. Canadian Journal of Forest Research, 37, 1349–1358.
Varner, J.M., Shearman, T.M., Kane, J.M., Banwell, E.M., Jules, E.S. & Stambaugh, M.C. (2022). Understanding flammability and bark thickness in the genus Pinus using a phylogenetic approach. Sci Rep, 12, 7384.
Vasquez, I.A. (2019). Restoring reciprocal relationships for social and ecological health. Ecology Law Quarterly, 46, 1049–1068.
Venier, L.A., Thompson, I.D., Fleming, R., Malcolm, J., Aubin, I., Trofymow, J.A., et al. (2014). Effects of natural resource development on the terrestrial biodiversity of Canadian boreal forests. Environmental Reviews, 22, 457–490.
Veracini, L. (2011). Introducing settler colonial studies. In: Settler Colonial Studies. Taylor & Francis Group, 1, 1–12.
Victor J., M. (2014). Fire management of the San Carlos Apache Tribe: a case study in southeastern Arizona. MS Thesis. Northern Arizona University.
Volney, W.J.A. & Fleming, R.A. (2000). Climate change and impacts of boreal forest insects. Agriculture, Ecosystems & Environment, 82, 283–294.
Vose, J.M. & Elliott, K.J. (2016). Oak, fire, and global change in the eastern USA: what might the future hold? Fire Ecology 12, 160-179.
Waldron, K., Ruel, J.-C. & Gauthier, S. (2013). The effects of site characteristics on the landscape-level windthrow regime in the North Shore region of Quebec, Canada. Forestry: An International Journal of Forest Research, 86, 159–171.
Walker, X.J., Baltzer, J.L., Cumming, S.G., Day, N.J., Ebert, C., Goetz, S., et al. (2019). Increasing wildfires threaten historic carbon sink of boreal forest soils. Nature, 572, 520–523.
Walker, X.J., Okano, K., Berner, L.T., Massey, R., Goetz, S.J., Johnstone, J.F., et al. (2023). Shifts in ecological legacies support hysteresis of stand type conversions in boreal forests. Ecosystems, 26, 1796–1805.
Wallenius, T.H., Pennanen, J. & Burton, P.J. (2011). Long-term decreasing trend in forest fires in northwestern Canada. Ecosphere, 2, art53.
Wang, X., Studens, K., Parisien, M.-A., Taylor, S.W., Candau, J.-N., Boulanger, Y., et al. (2020). Projected changes in fire size from daily spread potential in Canada over the 21st century. Environmental Research Letters, 15, 104048.
Ware, S., Frost, C.C. & Doerr, P.D. (1993). Southern mixed hardwood forest: the former longleaf pine forest. In: Biodiversity of the Southeastern United States: Lowland Terrestrial Communities. J. Wiley, New York, NY, 447–493.
Watts, A.C., Watts, D.L., Cohen, M.J., Heffernan, J.B., McLaughlin, D.L., Martin, J.B., et al. (2014). Evidence of biogeomorphic patterning in a low-relief karst landscape. Earth Surface

Processes and Landforms, 39, 2027–2037.
Wayman, R.B. & Safford, H.D. (2021). Recent bark beetle outbreaks influence wildfire severity in mixed-conifer forests of the Sierra Nevada, California, USA. Ecological Applications, 31, e02287.
Weatherspoon, C.P. & Skinner, C.N. (1995). An assessment of factors associated with damage to tree crowns from the 1987 wildfires in northern California. Forest Science, 41, 430–451.
Weatherspoon, P.C., Almond, G.A. & Skinner, C.N. (1989). Tree-centered spot firing-a technique for prescribed burning beneath standing trees. Western Journal of Applied Forestry, 4, 29–31.
Webster, P.J., Holland, G.J., Curry, J.A. & Chang, H.-R. (2005). Changes in tropical cyclone number, duration, and intensity in a warming environment. Science, 309, 1844–1846.
Weed, A.S., Ayres, M.P. & Hicke, J.A. (2013). Consequences of climate change for biotic disturbances in North American forests. Ecological Monographs, 83, 441–470.
Weisberg, P.J. (2009). Historical fire frequency on contrasting slope facets along the Mckenzie River, western Oregon Cascades. Western North American Naturalist, 69, 206–214.
Welch, K.R., Safford, H.D. & Young, T.P. (2016). Predicting conifer establishment post wildfire in mixed conifer forests of the North American Mediterranean-climate zone. Ecosphere, 7, e01609.
Wendel, R. & Zabowskl, D. (2010). Fire history within the lower Elwha River Watershed, Olympic National Park, Washington. Northwest Science, 84, 88–97.
Westbrook, J.W., Zhang, Q., Mandal, M.K., Jenkins, E.V., Barth, L.E., Jenkins, J.W., Grimwood, J., Schmutz, J. and Holliday, J.A. (2020). Optimizing genomic selection for blight resistance in American chestnut backcross populations: a trade- off with American chestnut ancestry implies resistance is polygenic. Evolutionary Applications, 13, 31-47.
Whitlock, C., Shafer, S.L. & Marlon, J. (2003). The role of climate and vegetation change in shaping past and future fire regimes in the northwestern US and the implications for ecosystem management. Forest Ecology and Management, 178, 5–21.
Whitman, E., Parisien, M.-A., Thompson, D.K. & Flannigan, M.D. (2019). Short-interval wildfire and drought overwhelm boreal forest resilience. Scientific Reports, 9, 18796.
Whitman, E., Parks, S.A., Holsinger, L.M. & Parisien, M.-A. (2022). Climate-induced fire regime amplification in Alberta, Canada. Environmental Research Letters, 17, 055003.
Whitney, G.G. & DeCant, J.P. (2003). Physical and historical determinants of the pre-and post-settlement forests of northwestern Pennsylvania. Canadian Journal of Forest Research, 33, 1683-1697.
Wieder, R.K., Vitt, D.H. & Benscoter, B.W. (2006). Peatlands and the Boreal Forest. In: Boreal Peatland Ecosystems, Ecological Studies (eds. Wieder, R.K. & Vitt, D.H.). Springer, Berlin, Heidelberg, 1–8.
Wilkins, D.E. & Lomawaima, K.T. (2002). Uneven Ground: American Indian Sovereignty and federal Law. University of Oklahoma Press, Norman, OK.
Williams, J.N., Safford, H.D., Enstice, N., Steel, Z.L. & Paulson, A.K. (2023). High-severity burned area and proportion exceed historic conditions in Sierra Nevada, California, and adjacent ranges. Ecosphere, 14, e4397.
Williams, M. (1992a). Americans and Their Forests: A Historical Geography. Cambridge University Press. Cambridge, United Kingdom.
Williams, R.A. (1992b). The American Indian in Western Legal Thought: The Discourses of Conquest. Oxford University Press, Oxford, United Kingdom.
Winthrop, K.R. (1993). Prehistoric settlement patterns in southwest Oregon. PhD Dissertation. University of Oregon, Eugene, OR.
Wohl, E. (2021). Legacy effects of loss of beavers in the continental United States. Environmental Research Letters, 16, 025010.
Woodall, C.W., Zhu, K., Westfall, J.A., Oswalt, C.M., D'Amato, A.W., Walters, B.F., et al. (2013). Assessing the stability of tree ranges and influence of disturbance in eastern US forests. Forest Ecology and Management, 291, 172–180.
Worrall, J.J., Rehfeldt, G.E., Hamann, A., Hogg, E.H., Marchetti, S.B., Michaelian, M., et al. (2013). Recent declines of Populus tremuloides in North America linked to climate. Forest Ecology and Management, 299, 35–51.
Wright, C.S. & Agee, J.K. (2004). Fire and vegetation history in the eastern Cascade Mountains, Washington. Ecological Applications, 14, 443–459.
Yazzie, V. (2007). The tribal perspective of old growth in frequent-fire forests—its history. Ecology and Society, 12.
Young, A.M., Higuera, P.E., Duffy, P.A. & Hu, F.S. (2017). Climatic thresholds shape northern high-latitude fire regimes and imply vulnerability to future climate change. Ecography, 40, 606–617.
Zampieri, N.E. & Pau, S. (2022). The effects of fire, climate, and species composition on longleaf pine stand structure and growth rates across diverse natural communities in Florida. Forest Ecology and Management, 526, 120568.
Zampieri, N.E., Pau, S. & Okamoto, D.K. (2020). The impact of Hurricane Michael on longleaf pine habitats in Florida. Scientific Reports, 10, 8483.
Zhu, K., Woodall, C.W. & Clark, J.S. (2012). Failure to migrate: lack of tree range expansion in response to climate change. Global Change Biology, 18, 1042–1052.

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