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Bringing justice to habitat conservation with Indigenous refugia: potential for planning and management of Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) in New Mexico

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In the face of climate change and associated increases in disturbances, some areas, known as refugia, will remain or become newly habitable for species, while others will be lost. Planning and managing for refugia can support biodiversity and conservation. However, without explicit consideration of justice, planning and management for refugia risks unnecessarily limiting information about local conditions and traditional practices that may be contained in Indigenous knowledges, and causing maladaptive consequences such as exclusion of Indigenous communities from decision-making and from protected areas, with loss of use of traditional plants and animals. The article proposes a new concept, Indigenous refugia, that incorporates three types of justice into existing theories of refugia for conservation in the face of climate change: recognition justice as understanding and respect for Indigenous values, experiences, and knowledges; procedural justice in collaboration and decision-making; and distributional justice as access to species and lands that sustain cultural and social processes. It presents a potential example of Indigenous refugia for the planning and management for climate-vulnerable Douglas-fir in New Mexico in collaboration with Pueblo, Diné (Navajo), Nde (Apache), and other Indigenous peoples with ancestral lands in the area.

KEYWORDS

climate change, refugia, justice, Indigenous knowledges, traditional uses, cultural resources, vulnerability, Douglas-fir

1 Introduction

Climate change is affecting species that we value intrinsically, that are integral parts of their ecosystems, and that meet the full range of human needs. As habitat changes, some areas, known as refugia, will remain or become newly habitable for species, communities, or ecosystems, while others will be lost.

Earlier research on refugia focused on species adapted to warmer conditions that were subjected to periods of glaciation. The emphasis was on understanding how past refugia supported the persistence and evolution of species, but the research also offered implications for future anthropogenic climate change (Dobrowski, 2011; Keppel et al., 2012). The current focus is on areas that will remain or become newly habitable in the face of current and future climate change, especially rising temperatures, changing hydrologic regimes, and increasing disturbance events (Ashcroft, 2010; Jackson, 2020; Morelli et al., 2020). Species may remain in these areas or retreat or migrate to them as the environment changes (Keppel et al., 2012, 2015; Krawchuk et al., 2020).

Refugia are typically formed as a result of distinctive topographies and associated microclimatic gradients, in areas protected from hot and cold extreme temperatures, and with favorable water regimes, such as wetlands, riparian areas, and groundwater-fed seeps and springs (Keppel et al., 2012; Morelli et al., 2016). Other species present in refugia may help buffer temperature and water balance, for example, vegetation may provide shade (Morelli and Millar, 2018). Areas that are protected from climate-related disturbances such as wildfires, floods, drought, and biotic events, such as insect outbreaks, can also serve as refugia (Morelli et al., 2016; Morelli and Millar, 2018; Krawchuk et al., 2020).

The literature on refugia emphasizes their value for ecological and evolutionary purposes, for biodiversity and conservation (Krawchuk et al., 2020; Morelli et al., 2020; Rossetto and Kooyman, 2021). Within that focus, there are variations in what is protected, from species to communities to ecosystems (Morelli et al., 2020); in the scale, from micro-refugia to macro-refugia (Ashcroft, 2010; Dobrowski, 2011); and in the threat, from incremental effects of climate change or more abrupt or extreme events, typically referred to as "disturbance refugia" (Krawchuk et al., 2020).

Refugia also have temporal variation, from "temporary refugia" that support recovery of surrounding areas after a disturbance, "persistent refugia" for longer-term preservation, and "future refugia" that are predicted to enable ongoing survival (Rossetto and Kooyman, 2021). They are generally not considered a solution for long-term survival of a species (Keppel et al., 2015; Morelli et al., 2016; Jackson, 2020). Rather, they can be considered a "slow lane," enabling persistence even while "embedded within faster climatic changes occurring in the broader landscape or region" (Morelli et al., 2020, p. 229).

2 Incorporating justice for Indigenous communities

Planning and management of refugia is a good fit with translational science, in which scientists and managers work together towards successful adaptation (Jackson, 2020). It can create opportunities for assistance from community scientists (Morelli et al., 2020). But while refugia might also protect sociocultural and physical resources, including archeological sites (Morelli et al., 2016, 2020), in addition to species, research and practice are not well developed in this area. Furthermore, there has been virtually no consideration of coordinating planning and management of refugia with Indigenous communities who may have distinctive interests in species, ecosystems, and features that may be defined as cultural resources. A single article comments that "In cases where Western scientific knowledge of climate-habitat-species relationships is available for species of significance to tribes, they can be crosslinked with tribal knowledge to better forecast and anticipate threats to tribal uses… and to identify possible refugia" (Long et al., 2018, p. 873). Management reports from a project in the Jemez Mountains of New Mexico, United States, also recommend coordination with Tribes regarding post-fire refugia (Stortz et al., 2017; Lehnert et al., 2021).

Climate change impacts on Indigenous communities are projected to be especially severe (Bennett et al., 2014). Coordinating planning and management of refugia with Indigenous communities could address this with work towards three types of climate justice: recognition, procedural, and distributional (Marino et al., 2023). As Armitage et al. (2020, p. 12) state, "Rights of indigenous and local communities in fact cannot be separated from conservation objectives, nor the efforts to redress and reconcile past injustices."

Supporting recognition justice would entail appreciating differences in worldviews between Indigenous and non-Indigenous peoples, including Indigenous relationships of reciprocity to other species (Whyte, 2013a; Kimmerer, 2018; Whyte et al., 2021) and those species' connections to Indigenous culture, social structures, and well-being (Whyte et al., 2018; Norgaard, 2019). Recognition justice would acknowledge that, for Indigenous peoples, futures associated with climate change build on the dystopian present associated with settler-colonialism (Whyte, 2017). It would also recognize value in multiple epistemologies, including Indigenous knowledges and western science (Johnson, 1992; McGregor, 2004), and the role of Indigenous knowledges in the collective continuance of Indigenous communities (Whyte, 2021).

Procedural justice would build on this understanding by meaningfully engaging Indigenous communities in all steps of planning and management for refugia, and supporting Indigenous engagement in environmental collaborations: respect for Indigenous knowledges, sovereignty over these knowledges, intergenerational involvement, self-determination, continuous cross-cultural education, and early involvement (Reo et al., 2017). Integrating Indigenous knowledges into planning and management for refugia would occur as a collaborative process (Whyte, 2013b), that recognizes risks and safeguards Indigenous communities against misuse, through best practices for free, prior, and informed consent (Climate and Traditional Knowledges Workgroup, 2014) and data sovereignty (Carroll et al., 2020). In the United States, engagement processes would move beyond federally mandated consultation processes (Blumm and Pennock, 2022) and limits of National Environmental Policy Act and National Historic Preservation Act requirements (Green and Cohn, 2023) and include the full range of decision making, with opportunities for Indigenous communities to design and lead their own initiatives (Armitage et al., 2020; Tran et al., 2020).

Distributional justice addresses the balance of burdens and benefits. If refugia were designated as protected areas, they could risk exclusion of Indigenous peoples and curtailment of their uses and management practices (Colchester, 1994), compounding histories of dispossession (Whyte, 2011, 2018) and also increasing climate change risks and hazards (Farrell et al., 2021). Indigenous peoples remain concerned about protected areas programs such as the Convention on Biological Diversity's proposal to commit at least 30% of lands to conservation by the year 2030, which does not recognize Indigenous peoples' potential concerns (Cultural Survival, 2021). Supporting distributional justice would ensure that Indigenous communities maintain access to species and lands, and are able to tend, harvest, prepare, and share them as part of social processes that sustain culture (Anderson, 1996; Norgaard, 2019).

I therefore propose a new concept, Indigenous refugia, that incorporates these three types of justice into current theories of refugia for conservation in the face of climate change: recognition justice as understanding and respect for Indigenous values, experiences, and knowledges; procedural justice in collaboration and decision-making; and distributional justice as access to species and lands that sustain cultural and social processes.

3 Climate vulnerability of Douglas-fir in New Mexico

The concept of Indigenous refugia can be applied to planning and management of species with distinct values for Indigenous peoples in particular areas, such as Douglas-fir (*Pseudotsuga menziesii*), a climate-vulnerable species in New Mexico, United States (Hausam and Henslee Peck, 2023). Douglas-fir is found throughout the western United States as two varieties, coastal, var. *menziesii*, and interior or Rocky Mountain, var. *glauca*. In New Mexico, Rocky Mountain Douglas-fir is found in forests between 8,000 and 9,500 feet in discontinuous areas. It is typically found on northerly exposures, though at high elevations it may grow on sunny slopes (Hermann and Lavender, 1990).

There are twenty-three federally recognized Tribes with jurisdictional authority within New Mexico's boundaries: nineteen Pueblos with three main language groups (Tano, which includes Tewa, Tiwa, and Towa; Keresan; and Zuni), the Navajo Nation (Diné people), Ft. Sill Apache Tribe, Jicarilla Apache Nation, and Mescalero Apache Tribe (Nde peoples). Federally recognized Comanche and Ute tribes, along with Tribes that are not federally recognized, such as the Genizaro, Piro, Manso, and additional Tiwa peoples, also have ancestral lands that are now within New Mexico.

Ethnobotanical studies have documented historical use of Douglas-fir by peoples from Isleta, Jemez, and Keresan (not specified) Pueblos, Apache, Navajo, Hopi, Tewa of Hano, Havasupai, and Gosiute, for ceremonial purposes (typically boughs or branches), various types of medicines, and candy, as well as trade (Moerman, 1998). Additional references document continued Pueblo use for dances and rituals (Ortiz, 1969; Scully, 1989; pers. obsv.) and Mescalero Apache use of tall, thin teepee poles made from Douglas-fir trees for a ceremony for young women (Mockta et al., 2018).

3.1 Temperature and drought

Douglas-fir in New Mexico is notably vulnerable to climate change. Projected temperature increases (Dixon et al., 2020) will drive drought based on greater evapotranspiration, reduced snowpack, and earlier runoff. Decreased soil moisture and reduced water balance stresses trees through interacting processes. Trees reduce evapotranspiration with stomatal closure, but this also reduces carbon dioxide intake for photosynthesis, which can lead to carbon starvation, decreased growth, and reduced ability to refill embolized xylem (Stephenson, 1990; McDowell et al., 2011; Restaino et al., 2016). In the Southwest, tree death may occur through rootlet mortality, diminished water transport, and prolonged xylem cavitation during drought (Swetnam and Betancourt, 1998). Douglas-fir tolerates some drought and has less vulnerability to xylem cavitation, but does not use some of the functional and structural approaches of the ponderosa pine (*Pinus ponderosa*) also found in this area (Stout and Sala, 2003).

3.2 Insects and pathogens

Warmer temperatures associated with climate change may accelerate insect outbreaks, especially if hard freezes become rarer and less effective at decreasing populations (Joyce et al., 2008). Drought can limit resin production, which decreases trees' ability to flush out insects (Allen et al., 2010), notably bark beetles. The most destructive bark beetle affecting Douglas-fir in New Mexico is the Douglas-fir beetle, *Dendroctonus pseudotsugae*, which feeds on phloem in its larval and adult stages. The Douglas-fir beetle prefers mature or over-mature forests and often attacks trees that are already stressed by drought, defoliation, root disease, or infestations of dwarf mistletoe, typically attacking new host trees in late spring to early summer (USDA Forest Service Southwestern Region, n.d.), which suggests that seasonal moisture levels might play a role in susceptibility. Large-scale Douglas-fir beetle outbreaks are rare in the Southwest, but may include groups of 100 or more trees (USDA Forest Service Southwestern Region, n.d.), and there has been increased activity in drought-stressed forests and forests surrounding recent fire scars in New Mexico.

In contrast to the Douglas-fir beetle, outbreaks of western spruce budworm, *Choristoneura occidentalis*, which feeds on the foliage and immature cones of Douglas-fir, true firs, and spruce, are correlated with increased spring precipitation (Swetnam and Lynch, 1993). This reflects availability of increased and softer foliage when trees are not under drought stress (Xu et al., 2019). Western spruce budworm is the most damaging defoliation agent in New Mexico and throughout the west. Increased forest density has increased the number of host trees and potential for outbreaks (Swetnam and Lynch, 1993). Temperature affects the overwinter survival of larvae, suggesting that as temperatures warm, more larvae may survive. The total area with western spruce budworm activity in New Mexico increased 58% between aerial surveys conducted in 2019 and 2020 (Formby, 2021). Repeated budworm defoliation over four or five years can ultimately lead to tree mortality, especially in smaller trees (Formby, 2021; USDA Forest Service Southwestern Region, n.d.). Trees weakened by western spruce budworm are also more vulnerable to bark beetles.

Douglas-fir trees in New Mexico are subject to a range of fungal diseases, including needle casts (*Rhabdocline* spp.), root rots (*Armillaria* spp., *Leptographium wageneri* var. *pseudotsugae*, *Phaeolus schweinitzii, Onnia tomentosa*), and heart rot and stem decays and stains (*Ophiostoma* spp., *Ceratocystis* spp., *Echinodontium tinctorum*, *Cryptodorus volvatus*, and *Fomitopsis pinicola*). Fungi, particularly *Armillaria*, often act in concert with other pests and pathogens, such as bark beetles (USDA Forest Service Southwestern Region, n.d.). Trees stressed due to effects of climate change are anticipated to become more susceptible to pathogens (Hanna et al., 2016).

3.3 Wildfire

Many forests of the western United States, including those with Douglas-fir in New Mexico, show evidence of fire exclusion and suppression such as high stem density, multi-layered canopies with more ladder fuels, and accumulation of surface fuels, which support more intense wildfires over larger areas in the future (Keane et al., 2002). As drought and insect outbreaks increase mortality, there is more fuel for more severe wildfires. Models predict statistically significant increases in very large wildfires in the Southwest (Stavros et al., 2014). Potential increases in extreme weather such as lightning storms and high winds increase risk of ignition and spread of wildfire.

Mature Douglas-fir's thick, corky bark and deep roots make it a fire-tolerant tree (Hermann and Lavender, 1990). Adult trees may survive to enable future regeneration, though likelihood of survival is reduced with increasing fire intensity. In the historical reference condition, Douglas-fir regenerated episodically, most likely after fire, in both warm-dry and cool-moist mixed conifer stands (Romme et al., 2009). However, Douglas-fir is slow-growing, with fire-tolerant traits not developing until later, making juvenile trees susceptible to fire for a longer time period than species such as ponderosa pine. Prior to European settlement, frequent fire maintained ponderosa pine rather than Douglas-fir in some regions because Douglas-fir did not reach a fire-resistant size before the next fire (Steinberg, 2002).

3.4 Post-fire re-establishment

The greatest climate change-related risk to Douglas-fir appears to be failure to reestablish following the intensive and large-scale wildfires that are predicted to increase due to climate change. Although Douglas-fir is tolerant of a wider range of environmental conditions for regeneration than ponderosa pine, does not require bare mineral soil, and may benefit from some competing vegetation to decrease temperature stress, these advantages are tempered by limited seed availability. Immature cones may be consumed by insects such as western spruce budworm (Hermann and Lavender, 1990). Cone crops vary from year to year (Hermann and Lavender, 1990), seed viability is limited to roughly 2 years (Steinberg, 2002), and seeds are often consumed by insects, birds, and mammals (Hermann and Lavender, 1990). Climate change impacts on phenology may also affect regeneration if cones and seeds are destroyed by damaging frost during cone anthesis (Hermann and Lavender, 1990). Douglas-fir seeds are relatively heavy and fall mostly within 330 feet of a seed tree (Hermann and Lavender, 1990), making regeneration within large burned areas unlikely and instead concentrating it in areas protected from fire and close to surviving trees (Steinberg, 2002; Hansen et al., 2018; Rodman et al., 2020). Regeneration of Douglas-fir following the Cerro Grande and Ponil Complex fires in New Mexico was greatest within refugia (Coop et al., 2019).

Douglas-fir seedlings are sensitive to soil moisture, which is expected to decrease, and surface temperature, projected to increase, limiting re-establishment (Swetnam and Betancourt, 1998; Joyce et al., 2008; Davis et al., 2018). Drought and high temperatures may narrow the time for effective regeneration (Joyce et al., 2008), and a "safe period" may be more important than "safe sites" (Addington et al., 2018). Temperature increases may also affect the phenology of growth and establishment of seedlings. Climate change's warming temperatures could lead to earlier bud burst but could also cause insufficient chilling and delayed growth. Delayed growth, in turn, may mean that seedlings do not capitalize on favorable soil moisture conditions in the spring (Harrington and Gould, 2015; Malmqvist et al., 2017).

New Mexico is at Douglas-fir's southernmost edge in the United States, thus losses there are expected to be severe, even though the overall niche for the species will decline only slightly (Rehfeldt et al., 2014; Mathys et al., 2016). Among mixed conifer-frequent fire ecosystem types in Arizona and New Mexico, only 20% will have low vulnerability, 43% moderate vulnerability, 22% high vulnerability, and 14% very high vulnerability to climate change, considering exposure and the likely changes in predominant vegetation features (Triepke et al., 2019). Models of future forests in areas of current use on Mescalero Apache land did not contain Douglas-fir after a century under even the mildest climate change scenario modeled, RCP 4.5, and projected complete forest mortality under RCP 6.0 and 8.5 (Mockta et al., 2018). Mortality is already exceeding gross growth for Douglas-fir in New Mexico (Goeking et al., 2014).

High-severity fire may cause a transition from forest species to shrub species, such as Gambel oak (*Quercus gambelii*), in northern New Mexico and throughout the southwest, as a long-term stable vegetation state, outcompeting conifers such as Douglas-fir (Guiterman et al., 2018; Keyser et al., 2020). For comparison, by the end of the 21st century, the Sandia Mountains near Albuquerque, which are now forested, may be similar to the Franklin Mountains by El Paso in the early century, without large trees (Gutzler, 2020).

The current extent of Douglas-fir, specifically fragmentation of its range, also affects its vulnerability. The U.S. Forest Service has described the entire state of New Mexico as a "land of sky islands" (USDA Forest Service Interior West Forest Service Inventory and Analysis, n.d.), isolated montane ecosystems, suggesting the challenges for regeneration and migration of the species to new areas.

3.5 Adaptive capacity

Adaptive capacity, the ability to adjust to climate change (US Global Climate Change Research Program, n.d.), is tied to intrinsic characteristics of a species, such as its interactions with other biota and its genetics, and extrinsic factors, such as resource management practices and funding.

Douglas-fir in New Mexico and throughout its habitat is affected by Douglas-fir mistletoe, *Arceuthobium douglasii*, a parasitic flowering plant that distorts branches into "brooms" and reduces growth and lifespan. Mistletoe is very common; twelve of thirty plots in a study on Douglas-fir within the Mescalero Apache Reservation in New Mexico were infested (Mockta et al., 2018). Dense brooms increase the likelihood of charring or torching of the tree during wildfire (Steinberg, 2002).

Rabbits and hares, beaver, pocket gophers, deer, and elk may damage Douglas-fir seedlings and saplings by browsing and clipping, and livestock may trample them. Bears may strip off bark and cambium from pole-sized timber (Hermann and Lavender, 1990).

Long-lived species with intra-population genetic variability and phenotypic plasticity, such as Douglas-fir, may survive decades of adverse conditions, if the rapidity of climate change does not exceed their limits (Hamrick, 2004). Douglas-fir's extensive range, including a variety in Mexico, suggests the likelihood of high genetic diversity within the species. However, as a long-lived species, Douglas-fir's rate of genetic adaptation may be comparatively low (Rodman et al., 2020).

Land use affects Douglas-fir's viability. Grazing reduces competition from grasses, favoring establishment of trees and temporarily reducing surface fuel, but also increasing long-term risks of intense wildfire due to denser forest stands (Belsky and Blumenthal, 1997; Steinberg, 2002). Livestock may also trample seedlings. Recreation and uncontrolled access, particularly where there are extensive road systems, can also lead to damage of individual trees and forests, especially through human ignition of wildfire. Industrial activities such as mining may affect forest health, and commercial development, often for housing, may convert forests to non-forest land. Water availability in the ecosystem is affected not only by precipitation levels but also historic and current practices that impacted hydrologic processes, such as improper road construction leading to erosion and incising of channels that reduces infiltration.

Effective management of forests and individual tree species requires financial and staffing resources. In New Mexico, wood harvests decreased by half over a 10 year period, and the forest products industry appears to be shrinking (Goeking et al., 2014), suggesting a risk of limited economic benefits that would drive allocation of funds for management (Vose et al., 2018). Although Douglas-fir is one of the most significant timber species in the United States, more timber operations harvest the coastal variety, var. *menziesii*, or are in the northern Rockies, so research focuses on those geographic areas.

However, effective management is also supported by collaboration and by recognition of the significance of climate change and its impacts, which are evident in the most recent New Mexico Forest Action Plan (New Mexico Energy Minerals and Natural Resources Department - Forestry Division, 2020). In New Mexico, the USDA Forest Service manages approximately 31% of forest land and the USDOI Bureau of Land Management manages approximately 12% of forest land. The Forest Service and other federal agencies manage 69% of the Douglas-fir group lands in New Mexico (Goeking et al., 2014).

4 Planning and management of Indigenous refugia for Douglas-fir

The value of Douglas-fir combined with its vulnerability to climate change suggest the need to plan for its habitat conservation in New Mexico. This section describes the seven steps of the Climate Change Refugia Conservation Cycle defined by Morelli et al. (2016, Table 1) with additions to support Indigenous refugia.

Step 1 – Define the planning purpose and objectives. These may include maintaining a specific ecosystem type or viable populations of a species for a certain period of time.

Incorporating recognition justice would entail recognizing the relationships and responsibilities that Indigenous communities – Pueblo, Apache, Navajo, and Tribes without land or federal recognition in New Mexico – have to forested lands and Douglas-fir, including the effects that dispossession and forced assimilation have had on those relationships. It would include setting objectives that honor, respect, and work to sustain or restore those relationships. Incorporating distributional justice would mean defining objectives for traditional uses, such as boughs and poles for ceremonial activity, as well as traditional management practices, enabling them as part of Indigenous responsibilities to the natural world and to the social well-being of their communities.

Step 2 – Assess climate impacts and vulnerabilities. These might include changes in temperature and hydrologic regimes, and their impacts at certain points in the life cycle; changes in vegetation; impacts on phenology; and changes in human activity, e.g., due to additional warm days for recreation. Species, community, and ecosystem vulnerability are linked to the characteristics of the landscape, while species vulnerability is also dependent on sensitivity associated with physiology and life cycle (Michalak et al., 2020).

Procedural justice for Indigenous refugia would include collaborating with Indigenous communities to understand the past, present, and future of Douglas-fir in New Mexico; using approaches that are associated with Indigenous knowledges, such as oral expression, observation, and hands-on experience; respecting holistic and intuitive thinking; and considering information that is localized, built on long-term experience and intergenerational teaching, and held collectively (Johnson, 1992). It would support additional research with Indigenous communities regarding traditional management of fire in areas of mixed conifers with Douglas-fir, building on recent studies (Roos et al., 2022), expanding into additional research topics, and following best practices for working with Indigenous knowledges in research (e.g., Climate and Traditional Knowledges Workgroup, 2014; David-Chavez and Gavin, 2018), while capitalizing on current federal support for integration of Indigenous knowledges into federal agency efforts (Lander and Mallory, 2021; Prabhakar and Mallory, 2022). This step could incorporate distributional justice by explicitly considering vulnerabilities and impacts associated with traditional uses and practices.

Step 3 – Review and revise conservation goals and objectives. Revisions might refine the area, communities, or species to be managed, the length of the management commitment, or other intentions, while considering whether the designation and management of refugia will be effective.

This step would also call for collaboration with Indigenous communities for meaningful engagement that goes beyond federally mandated consultation. It would integrate Indigenous communities' traditional uses and management practices for forested areas and Douglas-fir into all scales of planning documents, from nationwide policy directives, to individual National Forest plans, to detailed management area prescriptions and prescribed burn plans. It would incorporate additional details on how trees are used, e.g., partial use such as boughs versus entire trees for poles (Mockta et al., 2018).

Step 4 – Identify and map key refugia features. This step in the process defines the features that can create refugia, considering microclimates in temperature and water availability, vegetation, and fuel availability alongside information on the species, plus climate projections, to model potential refugia. Given the multiple factors creating heterogeneity that enable refugia, and the need for fine-scaled information, it is challenging to unify them in one model (Ackerly et al., 2020; Krawchuk et al., 2020; Michalak et al., 2020). This step also includes validating the models by comparing them with independent datasets (Barrows et al., 2020).

In this step, planning and management for Indigenous refugia would include integration of long-term and fine-scaled place-based Indigenous knowledges into mapping and modeling of potential Douglas-fir refugia; incorporation of areas needed for traditional uses and management practices into the models; and collaboration with Indigenous communities to validate models. As with other steps, this collaboration would need to follow best practices for working with Indigenous knowledges in research (e.g., Climate and Traditional Knowledges Workgroup, 2014; David-Chavez and Gavin, 2018).

Step 5 – Evaluate and prioritize refugial areas for specific management. This step designates the areas that are most likely to become refugia, and may also consider other factors important to species survival such as connectivity and size.

Prioritization of refugial areas would also include criteria to meet Indigenous communities' needs, such as supporting their ongoing relationships with Douglas-fir for traditional uses and management practices. This step would need to explicitly ensure that prioritization of refugia does not have maladaptive consequences such as limiting Indigenous access and use.

Step 6 – Identify and implement priority actions to manage climate change. This step may include a range of actions to protect and restore ecosystems and species in the areas prioritized as refugia. Actions may include protection, maintenance, and restoration, and are often not novel but prioritized for faster implementation in refugia (e.g., Smetzer and Morelli, 2019). Protection often plays a significant role. Morelli et al. (2016) suggest that publicly owned lands could be designated as "climate change refugia emphasis areas" in management plans, and Saunders et al. (2023) recommend expansion of formal protection areas to encompass refugia.

Management of refugia is often characterized as a "resistance" approach in the resist-accept-direct (Schuurman et al., 2020; Lynch et al., 2021) and the resistance-resilience-transformation frameworks (RRT; St-Laurent et al., 2021), because its intent is to preserve the existing characteristics of the ecosystem through protection (Morelli and Millar, 2018) *in-situ*. However, it may also be considered resilience in the RRT framework if there is re-introduction of species and habitat restoration, and transformation if it includes assisted range expansion from other areas into the refugium (Balantic et al., 2021), creating *ex-situ* refugia (Ashcroft, 2010).

For Indigenous refugia, this step would include continued collaboration with Indigenous communities to integrate their knowledges regarding appropriate management practices, including traditional and cultural methods, following best practices (e.g., Climate and Traditional Knowledges Workgroup, 2014; David-Chavez and Gavin, 2018). It would evaluate the full range of actions to reduce the risk to Douglas-fir, including addressing high tree density and fuel loads through mechanical thinning, prescribed fire, and allowing natural fire to occur within its historical range and variability (Addington et al., 2018; see Lehnert et al., 2021, for recommendations in the Jemez Mountains of New Mexico). Indigenous refugia would incorporate new information and implement traditional and cultural practices for managing fire; ensure that reducing density does not have maladaptive consequences for other plant and wildlife species and ecosystem functions, including those significant to Indigenous communities; and evaluate fire suppression as a tool for protecting designated refugia as seed sources and for Indigenous communities' uses.

This step would also evaluate actions to protect specific trees or stands, at small scales, through more intensive treatments for insect infestations (methylcyclohexanone and pyrethroids for Douglas-fir beetle, *Bacillus thuringensis* var. *kurstaki* for western spruce budworm), while considering toxicity to other insects such as bees (USDA Forest Service Southwestern Region, n.d.) and respecting Indigenous preferences.

To address the climate change-related risks of post-fire regeneration failure and seedling mortality, it will likely be necessary to plant Douglas-fir seedlings for reforestation (Rehfeldt et al., 2014), and in new areas. Assisted migration has risks, and stakeholders may be concerned about the limitations in the knowledge of complex forest ecology, uncertainty in climate projections, and challenges in the broader processes of forest governance (Findlater et al., 2022), but one article has suggested that the Mescalero Apache Tribe might choose to plant Douglas-fir seedlings on shaded aspects of Sierra Blanca, especially in microsites that do not face south and may have moister conditions, to ensure continued availability of pole-sized trees (Mockta et al., 2018). This action would include collaboration with Indigenous communities to collect seeds from a diversity of sources, since new characteristics may be favored (Joyce et al., 2008; Swanston et al., 2016).

Designating refugia would be maladaptive if it excluded Indigenous users and managers of Douglas-fir from certain areas. To avoid this, Indigenous refugia might include designation of exclusive Douglas-fir gathering areas and assurance of access on well-maintained roads on public lands, to promote tribal well-being (Long and Lake, 2018). Indigenous communities must also be involved in decision-making about other management actions related to support resilient refugia, such as wetland restoration and land use-specific approaches such as appropriately-sized and well-maintained road culverts and other infrastructure; sustainable livestock management and silvicultural methods; best practices for timber harvesting such as retaining woody debris to maintain moisture, soil quality, and nutrient cycling; recreation management and restrictions; and prevention of trespass.

Actions to support refugia necessarily also include policies, procedures, and enforcement; financial and staffing resources; and education. Policies should not only encourage refugia managed by state and federal agencies, but also refugia under the jurisdiction of Indigenous communities, with support for Indigenous leadership for these efforts (Tran et al., 2020). Financial and staffing resources could include increased and stable funding for the Tribal Forest Protection Act and Reserved Treaty Rights Lands Program for work on non-tribal lands to protect natural and cultural resources.

Step 7 – Monitor the effectiveness of designated refugia; realign objectives and actions. This step makes the Climate Change Refugia Conservation Cycle an iterative process with the potential for adaptive management.

For Indigenous refugia, this step would include collaboration Indigenous communities to define evaluation criteria that reflect their values and goals and metrics that reflect these criteria, and ensure that monitoring and evaluation of these criteria is funded and implemented. This step also requires that Indigenous communities be involved in iterative efforts.

Future planning and management with Indigenous communities could allow them to assess the potential of other tree species for specific uses. For example, the Mescalero Apache Tribe might explore the possibility of using another species for teepee poles (Mockta et al., 2018). Any consideration of substitutions must fully respect traditional and cultural needs and relationships, including any explicit and inviolable Indigenous responsibilities related to a particular species.

5 Conclusion

As Morelli et al. (2016) note, decisions regarding refugia "emphasize 'valued' resources for managers, who are often bound by both policies and public, place-based resource priorities and because, ultimately, all conservation is value-driven." These values should expand to include climate justice, framed as recognition, procedural, and distributional justice, for Indigenous communities. If refugia are planned and managed with the benefit of values and information from Indigenous knowledges, and support traditional Indigenous uses and management practices, they can serve both conservation and justice needs, as "Indigenous refugia." Such Indigenous refugia can help sustain resilience of Indigenous and non-Indigenous communities and the more-than-human world.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding author.

Author contributions

SH: Writing – review & editing, Writing – original draft, Investigation, Conceptualization.

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Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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