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REVIEW

Climate and land-use change impacts on cultural use berries: Considerations for mitigative stewardship

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Societal Impact Statement

Cultural use berries are prized foods and medicines across the United States and Canada, with almost 200 different species used by Indigenous Peoples. Berries are increasingly being impacted by environmental and land-use change. Berry habitats, how and when berry plants reproduce, and the volume of berries available for harvest each year are shifting widely. These changes are impacting access to, availability of, and consumption of berries. Biocultural stewardship practices, like low-intensity fire, transplanting, and thinning, can be used in response to these stressors to support berry plant health and productivity as well as a sustained relationship with this important food.

Summary

Almost 200 different species of berries are used for food and medicine by Indigenous Peoples, with unparalleled nutritional and cultural significance among plant foods. Environmental and land-use change is increasingly compromising access to, availability of, and consumption of berries. In this review, I consider (a) how climate and land-use change are impacting cultural use berries across species and places, as documented by Indigenous Peoples and in the scientific literature, and (b) how stewardship practices are being applied to promote resilience and sustainability in berrying landscapes experiencing stress. Climate impacts on Arctic and subarctic berry species include earlier ripening, changes in taste, or increased variability in abundance. These same regions are experiencing a proliferation of shrubs, while forests throughout the lower 48 and Canada are suffering from suffocating fuel loads and stand densities that are not conducive to berry habitat for many species. In the Pacific West, berries are influenced by prolonged droughts and increasing spring and summer temperatures. Climate change impacts are amplified by shifts in land use for forestry and agriculture. Biocultural stewardship practices, like low-intensity fire, thinning, transplanting, and cultural care, can be used to mitigate these impacts and promote berry microclimate habitats. There is opportunity for intertribal networking and knowledge sharing around berry stewardship practices that will support local and regional climate change responses.

KEYWORDS
biocultural stewardship, Canada, climate change, cultural use berries, land-use change, sustainability, United States

1 | INTRODUCTION

Wild berries are the most widely used plant food stewarded and consumed by Indigenous Peoples in the United States and Canada (Karst & Turner, 2011; Lantz & Turner, 2003; Migicovsky et al., 2022; Speller & Forbes, 2022; Weber, 2022). In his book, *Native American Ethnobotany*, Moerman (1998) documents approximately 162 different berry species used by Indigenous Peoples in North America. Berries grow in a multitude of habitats, from frozen tundra to prairies to bogs, and are vessels of food security, sovereignty, nutrition, and biocultural well-being. Many communities harvest hundreds of liters or gallons of berries annually (Minore et al., 1979; Parlee et al., 2005). Berries are one of the few naturally sweet wild foods (Turner, 2020) and coveted sources of plant-based carbohydrates paired with wild meat and fish proteins. They have phytochemicals that are immunoprotective and health promoting, with berries produced in extreme environments particularly rich in these compounds (Flint et al., 2011; Kellogg et al., 2010; Lila et al., 2012; McOliver et al., 2015).

Wild berries are increasingly being impacted by shifts in weather conditions (see Figure 1 and Table S1), documented through Indigenous knowledge and in the scientific literature (Ahmed et al., 2022). For example, Herman-Mercer et al. (2020) found that in the Yukon–Kuskokwim Delta region of Alaska, people are traveling further (on average, more than 20 miles from home) and to more places to pick berries. Berries are important phenological indicators of seasonal activities and cycles, with shifts in phenology impacting the predictability of resources and seasonal indicators (Lantz & Turner, 2003). Indigenous stewardship of berry plants, using practices like cultural fire, pruning and coppicing, and transplanting, supports berry habitat and productivity (Turner et al., 2013) but has been interrupted by colonial-implemented forest and land management practices focused on fire exclusion, homogeneity, monocropping, and privatization. The effects of land-use shifts amplify the impact of climate change today (Karuk Tribe – UC Berkeley Collaborative, 2023).

In this paper, I review the impacts of environmental and landscape change on berry species in the United States and Canada, as well as the role of biocultural stewardship in berry resilience and sustainability. Specifically, I ask: How are cultural use berry species being impacted by environmental and land-use change? How can stewardship practices be applied to promote resilience and sustainability in berrying landscapes experiencing stress?

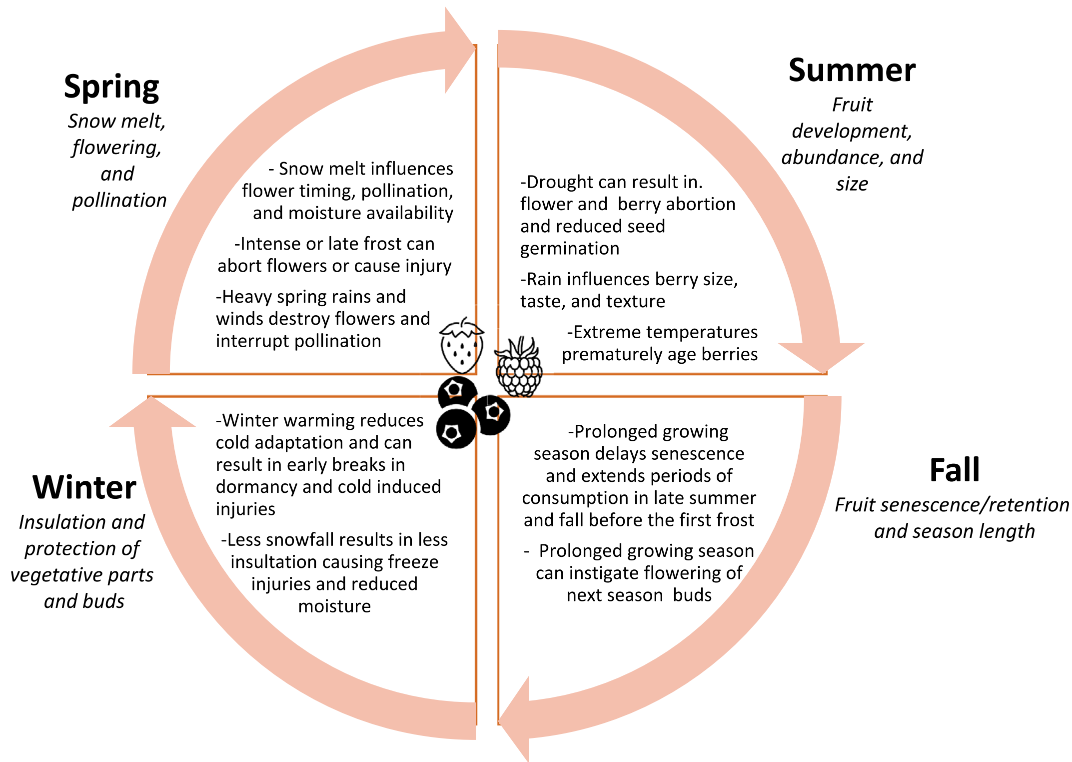

FIGURE 1 A model of common, seasonal climatic stressors or interruptions to berry production across species and regions in Alaska and Northern Canada. Some climatic conditions and interruptions are also applicable to temperate regions in the United States and Canada (e.g., heavy spring rains in the spring, drought conditions in the summer, or shifts in phenology).

2 | METHODS

This systematic review was developed through a multiple-step process that included compiling a list of cultural use berry species, a systematic literature search, a literature review and sorting, and laying the groundwork for depth in understanding. I used the Native American Ethnobotany Data Base (Moerman, 2003), based on Moerman's (1998) book *Native American Ethnobotany*, to compile a list of 162 berries used for food by Indigenous Peoples in the United States, many species and genres of which are also used in Canada. Starting with Latin and common berry names, I systematically searched peer-reviewed literature (Google Scholar and Web of Science) using a combination of terms: berry common or Latin name, climate change or land-use change, stewardship or management, and Native American/Alaska Native/Indigenous/First Nations. Three types of papers were aggregated: social environmental science studies focused on berries, studies broadly focused on climate change and Indigenous Peoples with small passages on berries, and natural science studies focused on things like botanical development, reproduction, or plot- or lab-based studies. One hundred thirty-five papers were reviewed, and the content was sorted into topical sections: geographic region, climate impacts, berry biology and reproduction, stewardship, and vegetation change. To supplement information on berry biology and reproduction, the Fire Effects Information System (USDA, 2023a) was consulted to shape Table S1. Synonymously, during this process, I worked closely with Indigenous berry pickers on the ground in California and Alaska as part of my primary research program, work that offered depth in understanding and interpretation for this review.

3 | CLIMATE CHANGE IMPACTS ON BERRIES

3.1 | Pacific west region

Black huckleberries (*Vaccinium membranaceum*) are a prolific fruit of the western United States and Canada and one of the most widely researched berry species of this region (Confederated Tribes of the Umatilla Indian Reservation, 2015; Forney, 2016; Hobby & Keefer, 2010; Wender et al., 2004). Species distribution models predict that suitable habitat for black huckleberry will diminish by 5%–40% across the northwestern United States by the end of the 21st century (Prevéy et al., 2020). Black huckleberry phenology is predicted to shift by over a month, with flowering advancing 23–50 days and fruiting advancing 24–52 days (Prevéy et al., 2020). A 20-year field plot study in Northern Idaho and Western Montana found that more black huckleberries were produced in years with cool springs and high July diurnal temperature ranges (Holden et al., 2012). Increasing minimum temperatures in the spring are negatively associated with berry production (Holden et al., 2012).

Cultural practitioners in the mid-Klamath River Basin observed green leaf manzanita (*Arctostaphylos patula*), blackcap raspberries (*Rubus leucodermis*), and evergreen huckleberries (*Vaccinium ovatum*) becoming brown and drying up early in the season from direct exposure to extreme heat and sun (Karuk Tribe – UC Berkeley Collaborative, 2023; Mucioki et al., 2024). Blackcap raspberries were also observed aborting and ripening asynchronously after extreme heat and then cold in early June. Harvesters in this same region have noticed that evergreen huckleberries are now ready in July, after being first harvested in September (Mucioki et al., 2022).

Communities in British Columbia have experienced years of complete berry failure, unusual flowering and fruiting, heavy spring rains that impact pollination, and increased rust disease in species like Saskatoon berry (*Amelanchier alnifolia*) and soapberry (*Shepherdia canadensis*) (Turner & Clifton, 2009). In places where there used to be an abundance of berries of different species, there is not one single berry today (Turner, 2003a). Lower productivity of berries for decades has been observed as a pattern across this region by berry pickers (Turner, 2003a).

3.2 | Arctic and subarctic regions

Berry production in the north can be highly productive (Hupp et al., 2013). However, production is increasingly variable and unpredictable (Hupp et al., 2015; Mulder et al., 2021; Spellman, 2019), and climate change is a concern for berry pickers (Flint et al., 2011). Early flowering or berrying was the most common and widespread (14 observations) berry-related climate anomaly reported by the Local Environmental Observer Network (Figure 2) (Alaska Native Tribal Health Consortium, 2016). Over 80% of berry pickers in the Yukon–Kuskokwim Delta region of Alaska said that salmonberries (*Rubus chamaemorus*) ripen earlier than they did 10 years ago; 50% observed blackberries (*Empetrum nigrum*) and blueberries (*Vaccinium* spp.) doing the same (Herman-Mercer et al., 2020). Similar experiences have been reported across Alaska (Bunce et al., 2016; Hupp et al., 2015). Decreasing abundance varies by species and microclimate (Herman-Mercer et al., 2020; Hupp et al., 2015; Siegwart Collier, 2020). Many berry species in this region develop fruit over 2 years, initiating flower buds in Year 1 and flowers and berries in Year 2 (Mulder et al., 2017), leaving them increasingly vulnerable to disruptions, like freeze injuries, illustrated in Figure 1 (Bokhorst et al., 2008). Today, berry pickers spend more time and money to find and travel to berry patches (Clark et al., 2016). Some are chartering flights ($200 round trip per person) to pick berries (Drolet, 2012).

Climate change is also impacting the taste and texture of berries. Over 50% of respondents in Iqaluit, Canada, said berries have been smaller, seedier, and less abundant since childhood, particularly in the last 3 years, hypothesizing that they are influenced by even small shifts in precipitation and temperature (Bunce et al., 2016). Snowfall and summer rainfall have decreased; drier conditions with warmer winter temperatures are linked to "diminishing" berry taste in Alaska and the Canadian North (Boulanger-Lapointe et al., 2019; Cuerrier et al., 2015; Kellogg et al., 2010). Pollution is also identified as a

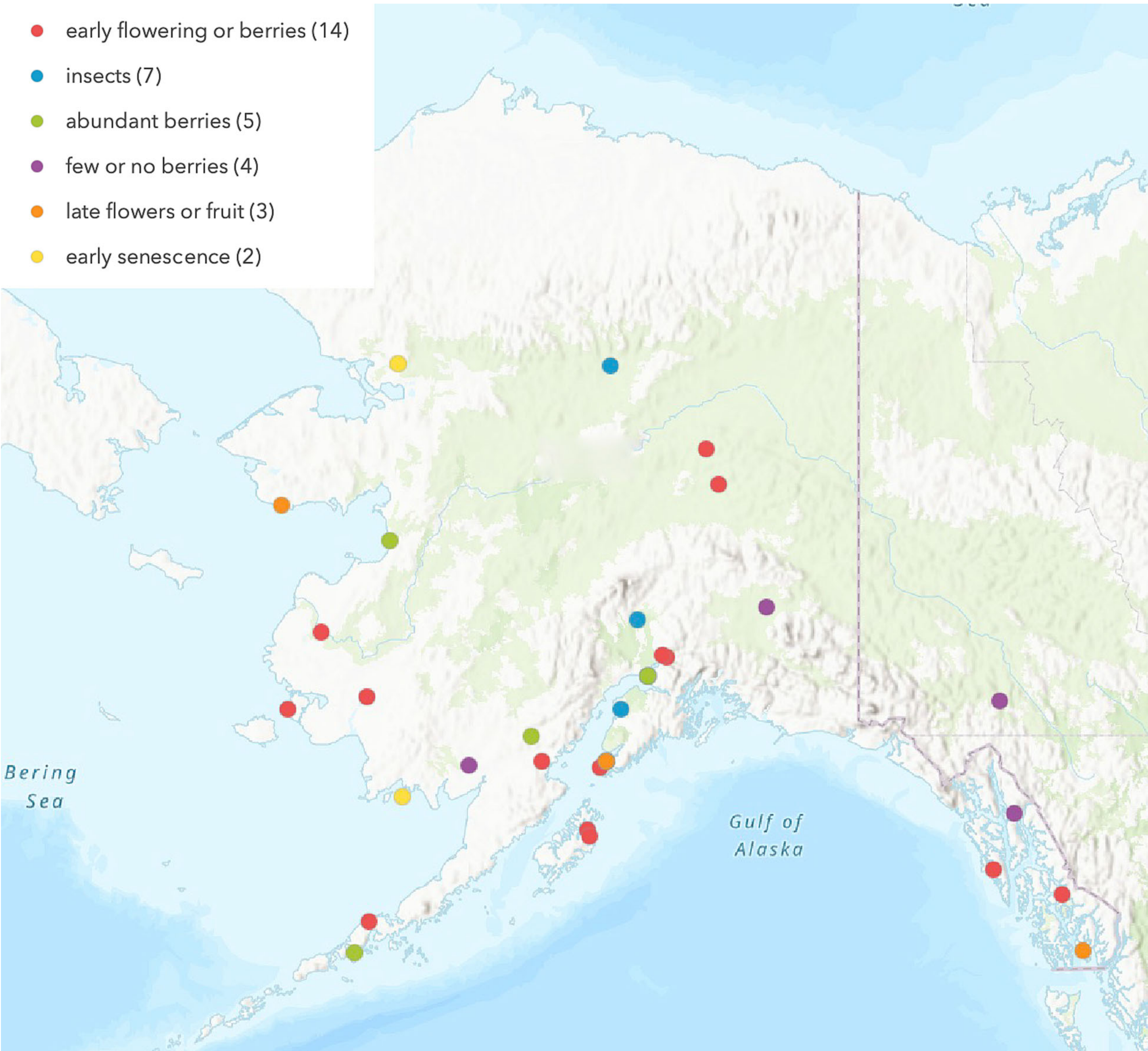

FIGURE 2 Observations of abnormalities in berry development and reproduction in Alaska and Northern Canada reported by berry pickers to the Local Environmental Observer Network (Alaska Native Tribal Health Consortium, 2016). Some points include multiple observations.

contributing factor to taste change (Boulanger-Lapointe et al., 2019). In some places, this is deterring consumption (Cuerrier et al., 2015; Nickels et al., 2006).

Inuit berry pickers in Canada said: "Traditionally, these resources were picked in the fall when temperatures are cooler, preserving them for longer. Now they ripen even in August leading to premature rotting" (Downing & Cuerrier, 2011). Heavy rains and heat observed by Teetl'it Gwich'in in the Northwest Territories, Canada, have caused berries to drop off plants when ripe, narrowing the harvest window. One picker delayed picking blueberries by a day and missed the harvest following a rainstorm (Parlee et al., 2006). This is also the case for salmonberries (Karst & Turner, 2011). In this region, biting insects have increased, and rainfall can compromise transportation to berry patches, deterring harvest even if the berries are present (Guyot et al., 2006).

Salmonberries are notably variable in production as they are more sensitive to extremes like strong winds (between 40 and 60 km/h) and heavy rains, late frost, or hot summer temperatures (above 25°C), particularly during flowering (Anderson et al., 2018; Karst, 2005; Karst & Turner, 2011; Norton et al., 2021; Parlee et al., 2006). One picker said: "cloudberries make us run around" (Karst & Turner, 2011). During years of extreme weather, sheltered microclimates under trees or shrubs sustain patches of salmonberries (Karst & Turner, 2011). In Cartwright, Labrador, the projected thaw of peatland permafrost threatens salmonberry habitat (Anderson et al., 2018; Way et al., 2018). In Kangiqsualujjuaq, salmonberries are growing taller and producing more fruits (Siegwart Collier, 2020).

The blackberry is the most steadily productive berry across years in these regions (González et al., 2019; Holloway, 2006; Hupp et al., 2013; Kellogg et al., 2010). Blackberry, along with bearberry

(*Arctostaphylos uva-ursi*), lingonberry (*Vaccinium vitis-idaea*), and soapberry, was monitored from 1997 to 2008 in the Yukon region. Over 11 years of monitoring, the most productive species was blackberry, with 1.5–4.6 times more berries produced than the aforementioned species (Krebs et al., 2009).

Increasing geese abundance in northern regions, resulting from more agricultural production along migration routes, has resulted in more berry (especially blackberry) consumption by geese (Boulanger-Lapointe et al., 2019; Hupp et al., 2013). On the other hand, berry abundance can impact goose hunting. If berries are not abundant, geese will be inaccessible to hunters (Downing & Cuerrier, 2011). Increasing agricultural potential and shifts in land use in the north are also predicted to compete with berry habitat (Hirabayashi et al., 2022). Additionally, warmer climates are more hospitable to invasive plant competitors like white sweet clover (*Melilotus albus*), which can compete for pollinators (Spellman et al., 2015).

3.3 | Eastern region

Berries used by Wabanaki people in Maine are simultaneously impacted by climate change and ongoing stressors from land grabbing, environmental pollution, and assimilation (Michelle, 2012, as cited in Lynn et al., 2013). Wild blueberry (*Vaccinium angustifolium* or *Vaccinium myrtilloides*) fields along the coast of Maine are warming at a greater rate during the growing season than the state as a whole (Tasnim et al., 2021); wild blueberry yields have decreased the last 6 years (Drummond & Yarborough, 2014). Barai et al. (2021) found that precipitation and evapotranspiration rates over the long term (more than 12 months) have a greater impact on blueberry vegetation growth and berry production than the conditions of the current growing season. Events of erratic frosts are happening with more frequency and are more often killing flowers and deterring fruiting of wild blueberries in Maine (Severson, 2019).

Large cranberries (*Vaccinium macrocarpon*) and small cranberries (*Vaccinium oxycoccos*) are adapted to flooding, although excessive flooding or winter flooding can exceed their adaptation (Hirabayashi et al., 2022). A Maxent model found annual temperature and precipitation accounted for >50% of the variability in large and small cranberry production. The timing of precipitation is more significant than the total amount of precipitation; precipitation will decrease in the wettest months but increase in the winter. This may cause excess water at the wrong time of year, leading to waterlogged soils (Hirabayashi et al., 2022).

4 | CHANGES IN BERRYING LANDSCAPES

4.1 | Shrubification

Tall and low-growing shrub (*Betula*, *Salix*, and *Alnus* spp.) cover and size are expanding in Arctic and subarctic regions, growth that is strongly correlated with warming and permafrost thaw (Elmendorf et al., 2012; Myers-Smith et al., 2011; Norton et al., 2021; Pearson et al., 2013). Few studies have explored the effects of increased canopy formation on dwarf shrub neighbors and particularly berries, with no consensus on impacts (Siegwart Collier, 2020). It is predicted that the strongest impacts will occur between species with a greater height differential (Siegwart Collier, 2020). Siegwart Collier (2020) found that in Inuit regions of Canada, increasing canopy from shrubification has the greatest impact on truly prostate berries (like lingonberry and blackberry) that have limited phenotypic plasticity in height growth. Berries that have greater height growth plasticity (like bog blueberry [*Vaccinium uliginosum*]) will have more ability to adapt through allocation trade-offs, although these trade-offs could impact berry productivity (Cuerrier et al., 2015; Siegwart Collier, 2020).

Sheltered microclimates shaped by shrubs create localized snow accumulation, resulting in the insulation of understory plants during the winter, delaying spring blooming and minimizing the risk of frost damage. These snow patches are also important sources of moisture for berries during spring and summer, particularly during hot and dry seasons (Boulanger-Lapointe et al., 2019). In northern Norway, snow fencing is intentionally constructed in open, windswept areas to increase snow on salmonberry fields (Holloway, 2006). Additionally, microclimates created by shrubs can allow for protection from temperature extremes and high winds and support the retention of soil moisture and pollinator habitat. Salmonberries growing in sheltered habitat have greater vegetative growth and more and larger fruits (Lohi, 1974; Myers-Smith et al., 2011; Yudina, 1993).

4.2 | Forest cover and density

Across the eastern and western regions, the most productive berry patches are often found in open and disturbed sites (Trusler & Johnson, 2008). Fire and biocultural stewardship suppression have shifted forest structure and berry habitat (Karuk Tribe – UC Berkeley Collaborative, 2023; Long et al., 2021), resulting in long-standing implications for berry abundance, with many patches diminished or existing only in vegetative form (Aleiss, 2018; Hobby & Keefer, 2010; Nielsen et al., 2020; Skinner, 1995). The impacts of fire suppression on berries have been widely documented, including in Coastal British Columbia (Turner, 2003a); red huckleberry (*Vaccinium parvifolium*) and evergreen huckleberry patches in Washington, Oregon, and California (Mucioki et al., 2022; Wender et al., 2004); salal (*Gaultheria shallon*) patches in Western Washington (Ballard & Huntsinger, 2006); black huckleberry throughout the west (Martin, 1983; Trusler & Johnson, 2008); and blackberry (*Rubus allegheniensis* and *Rubus canadensis*), raspberry (*Rubus idaeus*), and strawberry (*Fragaria* x *ananasa*) in Maine (Daigle et al., 2019). In the region of Port Graham, Alaska, Alaska blueberry (*Vaccinium alaskaense*) is more productive in spruce forests that have less tree density and lower tree basal area, letting in more light and posing less competition for space and resources (Reich et al., 2018). Spruce beetle infestations in southeast Alaska are contributing to the reduction of canopy cover to an extent that supports berry productivity for some species (Suring et al., 2008).

5 | RESPONDING TO ENVIRONMENTAL CHANGE WITH BERRY STEWARDSHIP

5.1 | Cultural or prescribed fire

Low-intensity fires have been widely used by Indigenous Peoples in the United States and Canada to steward the health and production of berries and berrying habitat (e.g., forest edges and openings and meadows and grasslands) (Christianson et al., 2022; Mucioki et al., 2024, 2022), particularly for *Vaccinium* and *Rubus* species (Deur, 2009; Gottesfeld, 1994; Long et al., 2021; Turner, 1999). Today, fire is being used to restore berry habitat. Berries like blackcap raspberries, wild raspberries, black huckleberry, low bush blueberry, and cranberries create more and larger berries following fire (Anderson, 2009; Duchesne & Wetzel, 2004; Hobby & Keefer, 2010; Lavoie & Pellerin, 2007; Turner, 2003a; Turner & Peacock, 2005). Ojibwe communities throughout Minnesota and Wisconsin describe going to berry patches in 1–2-year-old fire scars and finding huge expanses of blueberries in clusters and sizes equivalent to grapes (Norrgard, 2009). With environmental change, fire regimes are projected to shift with a higher incidence of fire across multiple regions (McCarty et al., 2021). At least in the short term, this will create earlier successional stages of forests that are more conducive to berry production for many species (Johnstone et al., 2010; Mack et al., 2008).

In Arctic and subarctic regions, more is known about fire management of berry species in boreal Canada than in Alaska (Christianson et al., 2022; Nelson et al., 2008). Communities (such as Anishnaabe, Gitksan, Wet'suwet'en, Dene, and Cree in Canada) use fire to maintain forest openings and renew the productivity, size, number, and sweetness of berries like currants, strawberries, raspberries, huckleberries, blueberries, and serviceberries (Berkes & Davidson-Hunt, 2006; Christianson et al., 2022; Davidson-Hunt, 2003). Inuit people in Labrador use fire to increase the productivity of lingonberry and bog blueberry for human and bear consumption (Oberndorfer, 2020); limited plot study data suggest that these same species in Arctic regions do increase post-fire (Nelson et al., 2008). The Gwich'in and Koyukon in interior Alaska are said to manage berry patches with fire as well (Natcher et al., 2007). However, for many berry pickers and researchers alike, the potential impacts on berries from fire and smoke in many Arctic places, including Alaska, have yet to be realized (Herman-Mercer et al., 2020). Berry species in tundra habitats are largely not fire adapted, many with shallow root or rhizome systems, and are slow to regenerate following fire (Lorion & Small, 2021; Table S1), taking multiple decades to recover and produce to pre-fire levels (Holloway, 2006; Mironov, 1984; Nelson et al., 2008).

5.2 | Thinning

Thinning removes encroaching vegetation and dead materials to maintain space and adequate sunlight for berry patch growth and access (Downing & Currier, 2011; Karuk Tribe – UC Berkeley Collaborative, 2023). Teetl'it Gwich'in blueberry pickers in the Northwest Territories, Canada, maintain their family picking spots by cutting back the willows encroaching on blueberry patches (Parlee et al., 2005, 2006). Removing overstory, in some cases, enables light exposure essential to berrying but, in other cases, can alter the microclimates to which understory plants are accustomed (Reich et al., 2018). Lingonberries are especially sensitive to overstory removal. In Sweden, lingonberry yield was reduced by 10% each year for the next decade following clear cutting (Holloway, 2006).

5.3 | Transplanting

Moving berry plants to facilitate accessible abundance and other forms of stewardship, like fertilizing and watering, are also done widely across species (e.g., wild strawberry [*Fragaria virginiana*], groundcherry [*Physalis* spp.], *Rubus* and *Vaccinium* species, serviceberry, red elderberry [*Sambucus racemose*], and highbush cranberries [*Viburnum edule*]) (Baumflek, 2015; Baumflek et al., 2021; Smith, 2011; Thornton, 1999; Turner, 2003b; Turner & Berkes, 2006; Turner & Loewen, 1998; Turner & Peacock, 2005). Westbank First Nation, in the Okanagan region of British Columbia, is transplanting thousands of black huckleberry plants annually to foster berry microhabitats in their territory (Migicovsky et al., 2022). The Karuk Tribe is restoring severely burned lands from wildfire with cuttings from black elderberry (*Sambucus nigra*) and other cultural use plants (personal communication, April 23, 2023).

5.4 | Cultural care and relationship

Practices of care and respect support berry sustainability and resilience (Boulanger-Lapointe et al., 2019). Some high bush cranberry patches are owned and inherited within families, with individuals leading the monitoring, harvest, and management to ensure longevity (Norton et al., 2021; Turner et al., 2013; Turner & Peacock, 2005). Berry pickers in Nunatsiavut, on the north coast of Labrador, and elsewhere never pick berries every day, all the berries in the patch, or more than they can use (Murray et al., 2005; Norton et al., 2021). Others rotate patches or avoid newly established patches (Boulanger-Lapointe et al., 2019). The Klamath Tribes, during the First Huckleberry Ceremony in Southern Oregon, scatter the first black huckleberry harvest on the ground as an act of reciprocity to ensure future harvests (Deur, 2009; Turner et al., 2011).

6 | THE FUTURE OF BERRIES

6.1 | Prioritize Indigenous-led stewardship of berries

Berries are a connecting strength among Indigenous Peoples across the United States and Canada; there are many opportunities to restore berries and support Indigenous sovereignty through stewardship, care, and a continued relationship with these important cultural foods. Practices of biocultural stewardship, like transplanting, thinning, and burning, can be applied to restore berry patches while enhancing resilience to climate change (Table 1 and Figure 1). Berries in the Pacific West United States and Canada are suffering from decades of fire suppression, denial of Indigenous stewardship practices, climate change, and resource extraction (see Elk & Baker, 2020). Many berry species in this region are responding well to the reintroduction of low-intensity burning, forest thinning, canopy removal, transplanting, and pruning practices, which also decrease the risk of wildfire and the impacts of drought on individual species.

6.2 | Increase agency awareness of cultural use species, habitat, and stewardship to support meaningful co-management opportunities

Some tribes have entered into co-management agreements with the US Forest Service to revitalize berry patches that are concurrently claimed as federal lands (see Dobkins et al., 2016; Paul, 2010); others in Canada and the United States are working with federal agencies to steward berry habitat and productivity through things like low-intensity fire and managing invasive species (see Sistering Indigenous and Western Science program pilot in Canada [Government of Canada, 2022]). Tribal co-stewardship programs in the United States are part of increasing government commitment to Indigenous food sovereignty (see USDA, 2023b), with 120 new co-stewardship agreements signed between the Forest Service and tribal governments in 2023 (USDA, 2023c). In Canada, Indigenous Protected Areas (Cyca, 2023), which prioritize things like berry productivity and health, are growing, with targeted goals for expansion by 2025 (Government of Canada, 2021). Workshops and programs for agency personnel that build awareness of cultural use foods, like berries, and biocultural stewardship practices and their importance are essential in supporting truly collaborative intergovernmental agreements and partnerships. Working in collaborative teams that include tribal leaders, agency personnel, and university researchers (see Karuk Resilience Initiative [Karuk Tribe – UC Berkeley Collaborative, 2023]) also provides the opportunity for cross pollination of knowledge and stewardship values and priorities.

TABLE 1 Berry environmental stressors and potential mitigative stewardship responses in regional or place-based climates in the United States and Canada.

Stressors	Mitigative stewardship
Xeric conditions	Promote dapple-shaded microclimates, snow accumulation for spring and summer moisture banking, and water berry patches when feasible
Canopy closure and shade	Low-intensity fire and manual thinning
Flooding and saltwater inundation in coastal areas	Transplanting, reseeding, and drainage
High-intensity fire and short fire return intervals	Low-intensity fire and manual thinning
Less insulative snow layer	Promote snow banking and accumulation on berry patches with snow fencing or shrubs
Late frost or freeze injury during warm and cold spells during spring	Promote microclimates that shelter and insulate to reduce early break in dormancy of berry plants and serve as protection
Increasing shrubs and invasive plants	Weed, thin, and continual use of berry patches
Filling in of open habitats like meadows, bogs, or grasslands	Low-intensity fire, manual thinning, and continual harvest and use

6.3 | Protect, promote, and establish berry microclimates

Biocultural stewardship creates microclimates, which are important landscape niches that provide protective resilience to berries in the face of drought and extreme weather (Table 1). Localized microclimates, not macroclimates, dictate the health and abundance of berry patches, making these species perfect recipients of Indigenous care connected to place. While shade and canopy can be inhibitive to some berry species (see Table S1), they are equally important to others for protection at different life phases (see Truscott, 2023). Areas under shrubs or small trees or along forest edges are abundant berry spots for species like salmonberry, as they act as buffers to weather events and uncertainties and provide prolonged moisture. Removal of the canopy, in some cases, can shift microclimates and stress berry patches or, in other cases, can be essential to berry production. Stewardship practices are species dependent and can be reflective of a biological affinity for some species to withstand things like disturbance, climate extremes, or mobility, coupled with stewardship practices intended to minimize vulnerabilities posed by things like intolerance of late-stage successional forest or freezing (see Table S1). Many of these berries have evolved with Indigenous stewardship practices that confirm their biological needs and minimize vulnerabilities to enhance productivity. Ex situ collections maintained by gene banks, herbaria, and botanical gardens complement in situ efforts and can support revitalization of lost in situ species (see Migicovsky et al., 2022, for more).

6.4 | Partner on research that explores the impacts of biocultural stewardship practices on cultural use berries in the context of climate stressors and land-use change

There are regions where less is known about the impact of climate change on berries and the impacts of biocultural stewardship for climate mitigation. The Pacific West and Northern/Alaska regions of Canada and the United States are berry-research-rich areas; other regions are under-researched. Literature in the eastern region often focuses on the agricultural production of wild blueberry or cranberry, generated due to commercial interest and economic viability. However, there is generally a lack of recognition of the role Indigenous Peoples play in blueberry and cranberry stewardship, particularly in terms of low-intensity fire, which is almost completely attributed to commercial growing cycles today. Little is known about the response of tundra and boreal edge habitats to wildfire and low-intensity fire, although there is limited evidence that some berry species respond with enhanced growth and berrying over long periods of recovery. Lengthy rebounds may limit the benefits of this management strategy. As wildfires occur with more frequency in the Arctic and subarctic, there is an opportunity to observe the impacts on berry patches over time. In Canada, the Strengthening Indigenous Research Capacity initiative focuses on co-developing directions and plans for Indigenous-led or co-produced research as part of the Truth and Reconciliation goals. Funding opportunities potentially suitable for berries are often limited by an emphasis on commercial or agricultural products or lands, excluding many Indigenous foods, landscapes, and ontologies. The USDA Applied Science Program supports integrated research projects, recently emphasizing environmental justice and Indigenous knowledge, but must shift further to be more inclusive of Indigenous food and environmental research needs, which are not commodity or agricultural crops.

6.5 | Facilitate intertribal learning opportunities to support cross pollination of berry stewardship practices in response to evolving environmental stressors

As the impacts of climate change and resulting vegetation shifts evolve, there will be a need for new stewardship practices. Indigenous networking around berries and stewardship may be beneficial at local and regional levels as climate impacts shift and evolve. For example, the Indigenous Foods Knowledges Network (2023) connected Indigenous communities in Alaska and the Southwest to build climate resilience; the Winterberry (2024) project uses citizen science volunteers throughout Alaska to document shifts in berrying. In Arctic and subarctic regions, increased vegetation and wildfires are posing interesting opportunities for intertribal exchange of experiences and practices with communities in the Pacific West, where fuel loading and canopy cover have been ongoing challenges for decades. Similarly, communities in the Eastern United States, where cultural fire is no longer practiced, may be interested in revitalizing the practice through intertribal knowledge sharing.

7 | CONCLUSION

Cultural use berries are experiencing shifts in abundance, quality/health, taste and phytonutrient compounds, reproduction, and habitat across Canada and the United States in ways that constrict harvest and consumption of these nutritious and culturally important plant foods. Intergenerational practices of land stewardship, like pruning, transplanting, or low-intensity fire, support predictable and consistent berry reproduction and health, quality, taste, and access. As Indigenous relationships with berries are bent and shifted by environmental stressors, stewardship practices can be used to insulate berries and berrying landscapes from the impacts. Community or family-level care that maintains species-dependent microclimates is a response centered on place-based skills and knowledge designed to co-evolve with dwelt in landscapes and the inherent biological resiliencies and vulnerabilities present across berry species. As berries continue their relationships with people, it may be useful for Indigenous berry harvesters and stewards to work as a network of leaders in these efforts, considering things like shifts in taste and palatability (and ultimately consumption), fire impacts in places like Alaska and tundra landscapes, and climate impacts in the eastern region, where evidence is lacking.

AUTHOR CONTRIBUTIONS

Megan Mucioki reviewed the literature and data and conceived and wrote the manuscript.

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CONFLICT OF INTEREST STATEMENT

The author declares no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in the Local Environmental Observer Network maintained by the Alaska Native Tribal Health Consortium at https://www.leonetwork.org/en/#lat=66.37275500247458&lng=-112.67578125&zoom=3&showing=7C499602-C40F-4089-A8D2-B7562C73CCE7&query=berry (accessed January 26, 2024).

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REFERENCES

Ahmed, S., Warne, T., Stewart, A., Byker Shanks, C., & Dupuis, V. (2022). Role of wild food environments for cultural identity, food security, and dietary quality in a rural American state. *Frontiers in Sustainable Food Systems*, *6*, 774701. https://doi.org/10.3389/fsufs.2022.774701

Alaska Native Tribal Health Consortium. (2016). Local Environmental Observer Network. Available from https://www.leonetwork.org/en/#lat=46.45299704748291&lng=-70.25756835937501&zoom=7&showing=BB32FF13-F20C-4B12-AC97-E263A30B3854 (Accessed January 22, 2024).

Aleiss, A. (2018). U.S. Forest Service and Tulalip Tribes partner for huckleberry enhancement project. *Tribal Relations News*. US Forest Service. Available from https://www.fs.usda.gov/spf/tribalrelations/documents/news/Winter2018TribalRelationsNews.pdf (accessed January 26, 2024).

Anderson, D., Ford, J. D., & Way, R. G. (2018). The impacts of climate and social changes on cloudberry (Bakeapple) picking: A case study from southeastern Labrador. *Human Ecology*, *46*, 849–863. https://doi.org/10.1007/s10745-018-0038-3

Anderson, K. (2009). The Ozette prairies of Olympic National Park: Their former Indigenous uses and management. Final Report to Olympic National Park Port Angeles, Washington. National Park Service, Pacific West Region. Available from https://www.nps.gov/olym/learn/management/upload/MKAnderson_Ozette_ONP_2009-df.pdf (Accessed January 26, 2024).

Ballard, H. L., & Huntsinger, L. (2006). Salal harvester local ecological knowledge, harvest practices and understory management on the Olympic Peninsula, Washington. *Human Ecology*, *34*, 529–547. https://doi.org/10.1007/s10745-006-9048-7

Barai, K., Tasnim, R., Hall, B., Rahimzadeh-Bajgiran, P., & Zhang, Y. J. (2021). Is drought increasing in Maine and hurting wild blueberry production? *Climate*, *9*(12), 178. https://doi.org/10.3390/cli9120178

Baumflek, M. (2015). Stewardship, health sovereignty and biocultural diversity: Contemporary medicinal plant use in indigenous communities of Maine, USA and New Brunswick, Canada. Cornell University. Doctoral Dissertation.

Baumflek, M., Kassam, K.-A., Ginger, C., & Emery, M. R. (2021). Incorporating biocultural approaches in forest management: Insights from a case study of Indigenous plant stewardship in Maine, USA and New Brunswick, Canada. *Society & Natural Resources*, *34*(9), 1155–1173. https://doi.org/10.1080/08941920.2021.1944411

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*(187), 35–47. https://doi.org/10.1111/j.1468-2451.2006.00605.x

Bokhorst, S., Bjerke, J. W., Bowles, F. W., Melillo, J., Callaghan, T. V., & Phoenix, G. K. (2008). Impacts of extreme winter warming in the sub-Arctic: Growing season responses of dwarf shrub heathland. *Global Change Biology*, *14*(11), 2603–2612. https://doi.org/10.1111/j.1365-2486.2008.01689.x

Boulanger-Lapointe, N., Gérin-Lajoie, J., Siegwart Collier, L., Desrosiers, S., Spiech, C., Henry, G. H. R., Hermanutz, L., Lévesque, E., & Cuerrier, A. (2019). Berry plants and berry picking in Inuit Nunangat: Traditions in a changing socio-ecological landscape. *Human Ecology*, *47*, 81–93. https://doi.org/10.1007/s10745-018-0044-5

Bunce, A., Ford, J., Harper, S., & Edge, V. (2016). Vulnerability and adaptive capacity of Inuit women to climate change: A case study from Iqaluit, Nunavut. *Natural Hazards*, *83*(3), 1419–1441. https://doi.org/10.1007/s11069-016-2398-6

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*(3), 257–276. https://doi.org/10.1007/s40725-022-00168-9

Clark, D. A., Workman, L., & Jung, T. S. (2016). Impacts of reintroduced bison on First Nations people in Yukon, Canada: Finding common ground through participatory research and social learning. *Conservation and Society*, *14*(1), 1–12. http://www.jstor.org/stable/26393223. https://doi.org/10.4103/0972-4923.182798

Confederated Tribes of the Umatilla Indian Reservation. (2015). Climate change vulnerability assessment. Available from https://ctuir.org/media/xe0ldtf5/ctuirclimatechangevulnerabilityassessmenttechnicalreportfinal.pdf (Accessed January 26, 2024).

Cuerrier, A., Brunet, N. D., Gérin-Lajoie, J., Downing, A., & Lévesque, E. (2015). The study of Inuit knowledge of climate change in Nunavik, Quebec: A mixed methods approach. *Human Ecology*, *43*, 379–394. https://doi.org/10.1007/s10745-015-9750-4

Cyca, M. (2023). The future of conservation in Canada depends on Indigenous protected areas. So what are they? *The Narwal*. Available from https://thenarwhal.ca/explainer-ipcas-canada/#:~:text=The%20three%20IPCAs%20recognized%20by,Indigenous%20and%20Territorial%20Protected%20Area (Accessed January 26, 2024).

Daigle, J. J., Michelle, N., Ranco, D. J., & Emery, M. R. (2019). Traditional lifeways and storytelling: Tools for adaptation and resilience to ecosystem change. *Human Ecology*, *47*, 777–784. https://doi.org/10.1007/s10745-019-00113-8

Davidson-Hunt, I. J. (2003). Indigenous lands management, cultural landscapes and Anishinaabe people of Shoal Lake, Northwestern Ontario, Canada. *Environments*, *31*(1), 21–42.

Deur, D. (2009). A caretaker responsibility: Revisiting Klamath and Modoc traditions of plant community management. *Journal of Ethnobiology*, *29*(2), 296–322. https://doi.org/10.2993/0278-0771-29.2.296

Dobkins, R., Lewis, C., Hummel, S., & Dickey, E. (2016). Cultural plant harvests on federal lands: Perspectives from members of the Northwest Native American Basketweavers Association. PNW-RP-608. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. Available from https://www.fs.usda.gov/pnw/pubs/pnw_rp608.pdf (Accessed January 26, 2024).

Downing, A., & Cuerrier, A. (2011). A synthesis of the impacts of climate change on the First Nations and Inuit of Canada. *Indian Journal of Traditional Knowledge*, *10*(1), 57–70. https://nopr.niscair.res.in/bitstream/123456789/11066/1/IJTK%2010(1)%2057-70.pdf (Accessed January 26, 2024)

Drolet, J. (2012). Climate change, food security, and sustainable development: A study on community-based responses and adaptations in British Columbia, Canada. *Community Development*, *43*(5), 630–644. https://doi.org/10.1080/15575330.2012.729412

Drummond, F. A., & Yarborough, D. E. (2014). Growing season effects on wild blueberry (*Vaccinium angustifolium*) in Maine and implications for management. *Acta Horticulturae*, *1017*, 101–107. https://doi.org/10.17660/ActaHortic.2014.1017.9

Duchesne, L. C., & Wetzel, S. (2004). Effect of fire intensity and depth of burn on lowbush blueberry, *Vaccinium angustifolium*, and velvet leaf blueberry, *Vaccinium myrtilloides*, production in eastern Ontario. *The Canadian Field-Naturalist*, *118*(2), 195–200. https://doi.org/10.22621/cfn.v118i2.913

Elk, L. B., & Baker, J. M. (2020). From traplines to pipelines: Oil sands and the pollution of berries and sacred lands from northern Alberta to North Dakota. In N. J. Tuner (Ed.), *Plants, people, and places: The roles of ethnobotany and ethnoecology in Indigenous peoples' land rights in Canada and beyond* (pp. 173–187). McGill-Queens University Press. https://doi.org/10.2307/j.ctv153k6x6

Elmendorf, S. C., Henry, G. H., Hollister, R. D., Björk, R. G., Boulanger-Lapointe, N., Cooper, E. J., Cornelissen, J. H., Day, T. A., Dorrepaal, E., Elumeeva, T. G., & Gill, M. (2012). Plot-scale evidence of tundra vegetation change and links to recent summer warming. *Nature Climate Change*, *2*(6), 453–457. https://doi.org/10.1038/nclimate1465

Flint, C. G., Robinson, E. S., Kellogg, J., Ferguson, G., BouFajreldin, L., Dolan, M., Raskin, I., & Lila, M. A. (2011). Promoting wellness in

Alaskan villages: Integrating traditional knowledge and science of wild berries. *EcoHealth*, *8*, 199–209. https://doi.org/10.1007/s10393-011-0707-9

Forney, A. (2016). Patterns of harvest: Investigating the social-ecological relationship between huckleberry pickers and black huckleberry (*Vaccinium membranaceum* Dougl. ex Torr.; Ericaceae) in southeastern British Columbia. University of Victoria. Doctoral Dissertation.

González, V. T., Moriana-Armendariz, M., Hagen, S. B., Lindgård, B., Reiersen, R., & Bråthen, K. A. (2019). High resistance to climatic variability in a dominant tundra shrub species. *PeerJ*, *7*, e6967. https://doi.org/10.7717/peerj.6967

Gottesfeld, L. M. J. (1994). Aboriginal burning for vegetation management in northwest British Columbia. *Human Ecology*, *22*, 171–188. https://www.jstor.org/stable/4603122. https://doi.org/10.1007/BF02169038

Government of Canada. (2021). Canada target 1 challenge. Available from https://www.canada.ca/en/environment-climate-change/services/nature-legacy/canada-target-one-challenge.html (Accessed January 22, 2024).

Government of Canada. (2022). Past Sistering Indigenous and Western Science projects. Available from https://natural-resources.canada.ca/our-natural-resources/indigenous-natural-resources/past-sistering-indigenous-and-western-science-projects/23941 (Accessed January 22, 2024).

Guyot, M., Dickson, C., Paci, C., Furgal, C., & Chan, H. M. (2006). Local observations of climate change and impacts on traditional food security in two northern Aboriginal communities. *International Journal of Circumpolar Health*, *65*(5), 403–415. https://doi.org/10.3402/ijch.v65i5.18135

Herman-Mercer, N. M., Loehman, R. A., Toohey, R. C., & Paniyak, C. (2020). Climate-and disturbance-driven changes in subsistence berries in coastal Alaska: Indigenous knowledge to inform ecological inference. *Human Ecology*, *48*, 85–99. https://doi.org/10.1007/s10745-020-00138-4

Hirabayashi, K., Murch, S. J., & Erland, L. A. (2022). Predicted impacts of climate change on wild and commercial berry habitats will have food security, conservation, and agricultural implications. *Science of the Total Environment*, *845*, 157341. https://doi.org/10.1016/j.scitotenv.2022.157341

Hobby, T., & Keefer, M. (2010). A black huckleberry case study in the Kootenays region of British Columbia. *BC Journal of Ecosystems and Management*, *11*(1 & 2), 52–61. https://cariboo-agricultural-research.ca/documents/CARA_lib_Hobby_Keefer_2010_A_Black_Huckleberry_Case_Study_in_the_Kootenays_Region_of_BC.pdf (Accessed February 11, 2024)

Holden, Z. A., Kasworm, W. F., Servheen, C., Hahn, B., & Dobrowski, S. (2012). Sensitivity of berry productivity to climatic variation in the Cabinet–Yaak grizzly bear recovery zone, Northwest United States, 1989–2010. *Wildlife Society Bulletin*, *36*(2), 226–231. https://doi.org/10.1002/wsb.128

Holloway, P. S. (2006). Managing wild bog blueberry, lingonberry, cloudberry, and crowberry stands in Alaska. University of Alaska Fairbanks. Natural Resources Conservation Service. Available from https://scholarworks.alaska.edu/bitstream/handle/11122/2828/MP%202007-01%20NRCS.pdf?sequence=1 (Accessed January 26, 2024).

Hupp, J., Brubaker, M., Wilkinson, K., & Williamson, J. (2015). How are your berries? Perspectives of Alaska's environmental managers on trends in wild berry abundance. *International Journal of Circumpolar Health*, *74*(1), 28704. https://doi.org/10.3402/ijch.v74.28704

Hupp, J. W., Safine, D. E., & Nielson, R. M. (2013). Response of cackling geese (*Branta hutchinsii taverneri*) to spatial and temporal variation in the production of crowberries on the Alaska Peninsula. *Polar Biology*, *36*, 1243–1255. https://doi.org/10.1007/s00300-013-1343-3

Indigenous Foods Knowledges Network. (2023). Cooperative Institute for Research in Environmental Sciences at the University of Colorado Boulder. Available from https://ifkn.org/ (Accessed January 26, 2024).

Johnstone, J. F., Chapin, F. S., Hollingsworth, T. N., Mack, M. C., Romanovsky, V., & Turetsky, M. (2010). Fire, climate change, and forest resilience in interior Alaska. *Canadian Journal of Forest Research*, *40*(7), 1302–1312. https://doi.org/10.1139/X10-061

Karst, A. (2005). The ethnoecology and reproductive ecology of bakeapple (*Rubus chamaemorus* L., Rosaceae) in Southern Labrador. University of Victoria. Dissertation. Available from https://dspace.library.uvic.ca/handle/1828/645

Karst, A. L., & Turner, N. J. (2011). Local ecological knowledge and importance of bakeapple (*Rubus chamaemorus* L.) in a southeast Labrador Métis Community. *Ethnobiology Letters*, *2*, 6–18. https://doi.org/10.14237/ebl.2.2011.28

Karuk Tribe – UC Berkeley Collaborative. (2023). Karuk Agroecosystem Resilience and Cultural Foods and Fibers Revitalization Initiative: xúus nu'éethti—We are caring for it. Karuk Aboriginal Territory. Karuk Tribe – UC Berkeley Collaborative. Berkeley, CA: University of California at Berkeley, and Orleans, CA: Karuk Department of Natural Resources. Available from https://nature.berkeley.edu/karuk-collaborative/wp-content/uploads/2023/03/Karuk-Resilience-Report_Smallest-file-size.pdf (Accessed January 26, 2024).

Kellogg, J., Wang, J., Flint, C., Ribnicky, D., Kuhn, P., De Mejia, E. G., Raskin, I., & Lila, M. A. (2010). Alaskan wild berry resources and human health under the cloud of climate change. *Journal of Agricultural and Food Chemistry*, *58*(7), 3884–3900. https://doi.org/10.1021/jf902693r

Krebs, C. J., Boonstra, R., Cowcill, K., & Kenney, A. J. (2009). Climatic determinants of berry crops in the boreal forest of the southwestern Yukon. *Botany*, *87*(4), 401–408. https://doi.org/10.1139/B09-013

Lantz, T. C., & Turner, N. J. (2003). Traditional phenological knowledge of Aboriginal peoples in British Columbia. *Journal of Ethnobiology*, *23*(2), 263–286.

Lavoie, C., & Pellerin, S. (2007). Fires in temperate peatlands (southern Quebec): Past and recent trends. *Botany*, *85*(3), 263–272. https://doi.org/10.1139/B07-012

Lila, M. A., Kellogg, J., Grace, M. H., Yousef, G. G., Kraft, T. B., & Rogers, R. B. (2012). Stressed for success: How the berry's wild origins result in multifaceted health protections. *Acta Horticulturae*, *1017*, 23–43. https://doi.org/10.17660/ActaHortic.2014.1017.1

Lohi, K. (1974). Variation between cloudberries (*Rubus chamemorus* L.) in different habitats. *Aquilo, Serie Botanica*, *13*, 1–9.

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. https://doi.org/10.1016/j.foreco.2021.119597

Lorion, J., & Small, E. (2021). Crowberry (*Empetrum*): A chief Arctic traditional Indigenous fruit in need of economic and ecological management. *The Botanical Review*, *87*, 259–310. https://doi.org/10.1007/s12229-021-09248-0

Lynn, K., Daigle, J., Hoffman, J., Lake, F., Michelle, N., Ranco, D., Viles, C., Voggesser, G., & Williams, P. (2013). The impacts of climate change on tribal traditional foods. *Climatic Change*, *120*, 545–556. https://doi.org/10.1007/s10584-013-0736-1

Mack, M. C., Treseder, K. K., Manies, K. L., Harden, J. W., Schuur, E. A. G., Vogel, J. G., Randerson, J. T., & Chapin, F. S. (2008). Recovery of aboveground plant biomass and productivity after fire in mesic and dry black spruce forests of interior Alaska. *Ecosystems*, *11*, 209–225. https://doi.org/10.1007/s10021-007-9117-9

Martin, P. (1983). Factors influencing globe huckleberry fruit production in northwestern Montana. *Bears: Their Biology and Management*, *5*, 159–165. https://doi.org/10.2307/3872533

McCarty, J. L., Aalto, J., Paunu, V. V., Arnold, S. R., Eckhardt, S., Klimont, Z., Fain, J. J., Evangeliou, N., Venäläinen, A., Tchebakova, N. M., & Parfenova, E. I. (2021). Reviews and syntheses: Arctic fire regimes and emissions in the 21st century. *Biogeosciences*, *18*(18), 5053–5083. https://doi.org/10.5194/bg-18-5053-2021

McOliver, C. A., Camper, A. K., Doyle, J. T., Eggers, M. J., Ford, T. E., Lila, M. A., Berner, J., Campbell, L., & Donatuto, J. (2015). Community-based research as a mechanism to reduce environmental health disparities in American Indian and Alaska Native communities. *International Journal of Environmental Research and Public Health*, *12*(4), 4076–4100. https://doi.org/10.3390/ijerph120404076

Migicovsky, Z., Amyotte, B., Ulrich, J., Smith, T. W., Turner, N. J., Pico, J., Ciotir, C., Sharifi, M., Meldrum, G., Stormes, B., & Moreau, T. (2022). Berries as a case study for crop wild relative conservation, use, and public engagement in Canada. *Plants, People, Planet*, *4*(6), 558–578. https://doi.org/10.1002/ppp3.10291

Minore, D., Smart, A. W., & Dubrasich, M. B. (1979). *Huckleberry and ecology management research in the Pacific Northwest*. Gen. Tech. Rep. PNW-GTR-093. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. Available from https://www.fs.usda.gov/pnw/pubs/pnw_gtr093.pdf (Accessed February 11, 2024).

Mironov, K. A. (1984). Recovery of bog bilberry and cranberry after ground fires. *Soviet Journal of Ecology*, *14*, 199–204.

Moerman, D. E. (1998). *Native American ethnobotany: Foods, drugs, dyes, and fibers of Native North American Peoples*. Timber Press.

Moerman, D. E. (2003). Native American ethnobotany. A database of foods, drugs, dyes and fibers of Native American Peoples, derived from plants. Botanical Research Institute of Texas. Available from http://naeb.brit.org/

Mucioki, M., Morehead-Hillman, L., McCovey, K., Sarna-Wojcicki, D., Lake, F. K., Bourque, S., Tripp, B., Hillman, L. G., & Sowerwine, J. (2024). Caring for culturally significant plants in the midst of record setting droughts. *Artemisia*, *49*(2).

Mucioki, M., Sowerwine, J., Sarna-Wojcicki, D., McCovey, K., & Bourque, S. D. (2022). Understanding the conservation challenges and needs of culturally significant plant species through Indigenous Knowledge and species distribution models. *Journal for Nature Conservation*, *70*, 126285. https://doi.org/10.1016/j.jnc.2022.126285

Mulder, C. P., Iles, D. T., & Rockwell, R. F. (2017). Increased variance in temperature and lag effects alter phenological responses to rapid warming in a subarctic plant community. *Global Change Biology*, *23*(2), 801–814. https://doi.org/10.1111/gcb.13386

Mulder, C. P., Spellman, K. V., & Shaw, J. (2021). Berries in winter: A natural history of fruit retention in four species across Alaska. *Madrono*, *68*(4), 487–510. https://doi.org/10.3120/0024-9637-68.4.487

Murray, G., Boxall, P. C., & Wein, R. W. (2005). Distribution, abundance, and utilization of wild berries by the Gwich'in people in the Mackenzie River Delta Region. *Economic Botany*, *59*(2), 174–184. https://www.jstor.org/stable/4256962. https://doi.org/10.1663/0013-0001(2005)059[0174:DAAUOW]2.0.CO;2

Myers-Smith, I. H., Forbes, B. C., Wilmking, M., Hallinger, M., Lantz, T., Blok, D., Tape, K. D., Macias-Fauria, M., Sass-Klaassen, U., Lévesque, E., & Boudreau, S. (2011). Shrub expansion in tundra ecosystems: Dynamics, impacts and research priorities. *Environmental Research Letters*, *6*(4), 045509. https://doi.org/10.1088/1748-9326/6/4/045509

Natcher, D. C., Calef, M., Huntington, O., Trainor, S., Huntington, H. P., DeWilde, L. O., Rupp, S., & Chapin, F. S. III (2007). Factors contributing to the cultural and spatial variability of landscape burning by native peoples of interior Alaska. *Ecology and Society*, *12*(1) https://www.jstor.org/stable/26267834, art7. https://doi.org/10.5751/ES-01999-120107

Nelson, J. L., Zavaleta, E. S., & Chapin, F. S. (2008). Boreal fire effects on subsistence resources in Alaska and adjacent Canada. *Ecosystems*, *11*, 156–171. https://doi.org/10.1007/s10021-007-9114-z

Nickels, S., Furgal, C., Buell, M., & Moquin, H. (2006). Unikkaaqatigiit—Putting the human face on climate change: Perspectives from Inuit of Canada. Ottawa: Joint publication of Inuit Tapiriit Kanatami, Nasivvik Centre for Inuit Health and Changing Environments at Université Laval and the Ajunnginiq Centre at the National Aboriginal Health Organization. Available from https://www.itk.ca/wp-content/uploads/2016/07/Nunavik.pdf (Accessed January 26, 2024).

Nielsen, S. E., Dennett, J. M., & Bater, C. W. (2020). Predicting occurrence, abundance, and fruiting of a cultural keystone species to inform landscape values and priority sites for habitat enhancements. *Forests*, *11* (7), 783. https://doi.org/10.3390/f11070783

Norrgard, C. (2009). From berries to orchards: Tracing the history of berrying and economic transformation among Lake Superior Ojibwe. *American Indian Quarterly*, *33*(1), 33–61. https://www.jstor.org/stable/25487918. https://doi.org/10.1353/aiq.0.0035

Norton, C. H., Cuerrier, A., & Hermanutz, L. (2021). People and plants in Nunatsiavut (Labrador, Canada): Examining plants as a foundational aspect of culture in the Subarctic. *Economic Botany*, *75*(3–4), 287–301. https://doi.org/10.1007/s12231-021-09530-7

Oberndorfer, E. (2020). What the blazes!? A people's history of fire in Labrador. *Journal of the North Atlantic*, *40*, 1–16. https://doi.org/10.3721/037.006.4001

Parlee, B., Berkes, F., & Teetl'it Gwich'in Renewable Resources Council. (2006). Indigenous knowledge of ecological variability and commons management: A case study on berry harvesting from Northern Canada. *Human Ecology*, *34*, 515–528. https://doi.org/10.1007/s10745-006-9038-9

Parlee, B., Berkes, F., & Teetl'it Gwich'in Renewable Resources Council. (2005). Health of the land, health of the people: A case study on Gwich'in berry harvesting in northern Canada. *EcoHealth*, *2*, 127–137. https://doi.org/10.1007/s10393-005-3870-z

Paul, A. (2010). Forest Service wants to boost huckleberries. *Albany Democrat-Herald Newspaper*. Available from https://democratherald.com/news/local/forest-service-wants-to-boost-huckleberries/article_e2631f2c-0fe6-11e0-a692-001cc4c03286.html (Accessed January 26, 2024).

Pearson, R. G., Phillips, S. J., Loranty, M. M., Beck, P. S., Damoulas, T., Knight, S. J., & Goetz, S. J. (2013). Shifts in Arctic vegetation and associated feedbacks under climate change. *Nature Climate Change*, *3*(7), 673–677. https://doi.org/10.1038/nclimate1858

Prevéy, J. S., Parker, L. E., Harrington, C. A., Lamb, C. T., & Proctor, M. F. (2020). Climate change shifts in habitat suitability and phenology of huckleberry (*Vaccinium membranaceum*). *Agricultural and Forest Meteorology*, *280*, 107803. https://doi.org/10.1016/j.agrformet.2019.107803

Reich, R. M., Lojewski, N., Lundquist, J. E., & Bravo, V. A. (2018). Predicting abundance and productivity of blueberry plants under insect defoliation in Alaska. *Journal of Sustainable Forestry*, *37*(5), 525–536. https://doi.org/10.1080/10549811.2018.1433047

Severson, K. (2019). From apples to popcorn, climate change is altering the foods America grows. *New York Times*. Available from https://www.nytimes.com/2019/04/30/dining/farming-climate-change.html (Accessed January 26, 2024).

Siegwart Collier, L. (2020). Climate change impacts on berry shrub performance in treeline and tundra ecosystems. Memorial University of Newfoundland. Doctoral Dissertation.

Skinner, C. N. (1995). Change in spatial characteristics of forest openings in the Klamath Mountains of northwestern California, USA. *Landscape Ecology*, *10*(4), 219–228. https://doi.org/10.1007/BF00129256

Smith, B. D. (2011). General patterns of niche construction and the management of 'wild' plant and animal resources by small-scale pre-industrial societies. *Philosophical Transactions of the Royal Society, B: Biological Sciences*, *366*(1566), 836–848. https://doi.org/10.1098/rstb.2010.0253

Speller, J., & Forbes, V. (2022). On the role of peat bogs as components of Indigenous cultural landscapes in Northern North America. *Arctic, Antarctic, and Alpine Research*, *54*(1), 96–110. https://doi.org/10.1080/15230430.2022.2049957

Spellman, K. (2019). Alaska's berries and their changing seasons. UAF Summer Sessions and Lifelong Learning. Available from https://www.youtube.com/watch?v=62C18zevNN0 (Accessed January 26, 2024).

Spellman, K. V., Schneller, L. C., Mulder, C. P., & Carlson, M. L. (2015). Effects of non-native *Melilotus albus* on pollination and reproduction in two boreal shrubs. *Oecologia*, *179*, 495–507. https://doi.org/10.1007/s00442-015-3364-9

Suring, L. H., Goldstein, M. I., Howell, S. M., & Nations, C. S. (2008). Response of the cover of berry-producing species to ecological factors on the Kenai Peninsula, Alaska, USA. *Canadian Journal of Forest Research*, *38*(5), 1244–1259. https://doi.org/10.1139/X07-229

Tasnim, R., Drummond, F., & Zhang, Y. J. (2021). Climate change patterns of wild blueberry fields in Downeast, Maine over the past 40 years. *Water*, *13*(5), 594. https://doi.org/10.3390/w13050594

Thornton, T. F. (1999). Tleikwaani, the "berried landscape" the structure of Tlingit edible fruit resources at Glacier Bay, Alaska. *Journal of Ethnobiology*, *19*(1), 27–48.

Truscott, S. (2023). Forest debris could shelter huckleberry from climate change. *WSU Insider*. Available from https://news.wsu.edu/news/2023/01/27/forest-debris-could-shelter-mountain-huckleberry-from-climate-change/ (Accessed January 26, 2024).

Trusler, S., & Johnson, L. M. (2008). "Berry patch" as a kind of place—The ethnoecology of black huckleberry in northwestern Canada. *Human Ecology*, *36*, 553–568. https://doi.org/10.1007/s10745-008-9176-3

Turner, N. (2003b). Passing on the news: Women's work, traditional knowledge and plant resource management in Indigenous societies of North-Western North America. In P. Howard (Ed.), (1999)*Women and plants* (pp. 133–149). Zed Books.

Turner, N. J. (1999). "Time to burn": Traditional use of fire to enhance resource production by Aboriginal Peoples in British Columbia. In R. Boyd (Ed.), *Indians, fire and the land in the Pacific Northwest* (pp. 185–218). Oregon State University Press. http://faculty.washington.edu/stevehar/TurnerBurner.pdf (Accessed January 26, 2024)

Turner, N. J. (2003a). "Not one single berry": Indigenous knowledge and environmental change in British Columbia. CINE symposium, October 15th. Session on Working with Indigenous Peoples to Document Environmental Change. Available from https://www.mcgill.ca/cine/files/cine/turner.pdf (Accessed January 26, 2024).

Turner, N. J. (2020). "That was our candy!": Sweet foods in Indigenous peoples' traditional diets in Northwestern North America. *Journal of Ethnobiology*, *40*(3), 305–327. https://doi.org/10.2993/0278-0771-40.3.305

Turner, N. J., & Berkes, F. (2006). Coming to understanding: Developing conservation through incremental learning in the Pacific Northwest. *Human Ecology*, *34*, 495–513. https://doi.org/10.1007/s10745-006-9042-0

Turner, N. J., & Clifton, H. (2009). "It's so different today": Climate change and Indigenous lifeways in British Columbia, Canada. *Global Environmental Change*, *19*(2), 180–190. https://doi.org/10.1016/j.gloenvcha.2009.01.005

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*(1), 4–43. https://doi.org/10.2993/0278-0771-31.1.4

Turner, N. J., Lepofsky, D., & Deur, D. (2013). Plant management systems of British Columbia's First Peoples. *BC Studies: The British Columbian Quarterly*, *179*, 107–133. https://doi.org/10.14288/bcs.v0i179.184112

Turner, N. J., & Loewen, D. C. (1998). The original "free trade": Exchange of botanical products and associated plant knowledge in northwestern North America. *Anthropologica*, *40*(1), 49–70. https://www.jstor.org/stable/25605872. https://doi.org/10.2307/25605872

Turner, N. J., & Peacock, S. (2005). Solving the perennial paradox: Ethnobotanical evidence for plant resource management on the Northwest Coast. In D. Duer & N. J. Turner (Eds.), *Keeping it living: Traditions of plant use and cultivation on the Northwest Coast of North America* (pp. 101–150). University of Washington Press.

USDA. (2023a). Fire effects information system. USDA and US Forest Service. Available from https://www.feis-crs.org/feis/ (Accessed January 26, 2024).

USDA. (2023b). USDA Indigenous Food Sovereignty Initiative. USDA. Available from https://www.usda.gov/tribalrelations/usda-programs-and-services/usda-indigenous-food-sovereignty-initiative (Accessed January 26, 2024).

USDA. (2023c). At White House Tribal Nations Summit, USDA fulfills long-standing tribal requests to strengthen food sovereignty and expand Indigenous roles in forest management. USDA. Available from https://www.usda.gov/media/press-releases/2023/12/06/white-house-tribal-nations-summit-usda-fulfills-long-standing (Accessed January 26, 2024).

Way, R. G., Lewkowicz, A. G., & Zhang, Y. (2018). Characteristics and fate of isolated permafrost patches in coastal Labrador, Canada. *The Cryosphere*, *12*(8), 2667–2688. https://doi.org/10.5194/tc-12-2667-2018

Weber, J. T. (2022). Traditional uses and beneficial effects of various species of berry-producing plants in eastern Canada. *Botany*, *100*(2), 175–182. https://doi.org/10.1139/cjb-2021-0086

Wender, B. W., Harrington, C. A., & Tappeiner, J. C. (2004). Flower and fruit production of understory shrubs in western Washington and Oregon. *Northwest Science*, *78*(2), 124–140. https://www.fs.usda.gov/research/sites/default/files/2023-03/pnw-490_wenderetal2004.pdf (Accessed January 26, 2024)

Winterberry. (2024). Winterberry: Citizen science for understanding berries in a changing north. Available from https://sites.google.com/alaska.edu/winterberry/home (Accessed January 26, 2024).

Yudina, V. F. (1993). Phenological development and yields of cloudberry, (*Rubus chamaemorus*) in Karelia, Russia. *Acta Botanica Fennica*, *149*, 7–10.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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