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Native and agricultural forests at risk to a changing climate in the Northern Plains

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Abstract Native and agricultural forests in the Northern Plains provide ecosystem services that benefit human society—diversified agricultural systems, forest-based products, and rural vitality. The impacts of recent trends in temperature and disturbances are impairing the

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delivery of these services. Climate change projections identify future stressors of greater impact, placing at risk crops, soils, livestock, biodiversity, and agricultural and forest-based livelihoods. While these native and agricultural forests are also a viable option for providing mitigation and adaptation services to the Northern Plains, they themselves must be managed in terms of climate change risks. Because agricultural forests are planted systems, the primary approaches for reducing risks are through design, plant selection and management. For native forests, management, natural disturbances, and collaboration of multiple ownerships will be needed to address key risks.

1 Native and agricultural forests in the Northern Plains

The Northern Plains region encompasses the states of Montana, Wyoming, Colorado, North and South Dakota, and Nebraska. Despite the region's name, forests have played important roles in the ecology and the local economy since the 1800s (McKay 1994). Native forest refers to large continuous tracts of natural or managed forests. These forests occur in western and central Montana, Wyoming and Colorado, on isolated mountain ranges such as the Black Hills of South Dakota, as hardwood forests in eastern North and South Dakota and Nebraska, and as riparian forests along rivers, lakes, and streams throughout the region. Although only occupying 17% of the region's land area, native forests play a key role in providing wildlife habitat and wood materials, rural vitality, and as primary buffers for watersheds and riparian areas (CSFS 2010; DNRC 2010; Kotchman 2010; WSFD 2010; SDDA 2010; Nebraska Forest Service 2015). Agricultural forest resources occur throughout the Northern Plains. Highly fragmented forests can be naturally occurring or planted as woodlots on farm and pasture land, but generally do not meet the size/area criteria of inventories to qualify as "forests" per se. In addition, agricultural forest resources include trees deliberately grown in association with crops and pastures, a practice called agroforestry (see Supplementary Table 1). These agricultural forest resources can comprise up to 50% of the tree resources in several of the Northern Plains states (Schoeneberger et al. 2016). Across the region, these agricultural forests provide many valued forest-based services in support of agricultural operations, natural resource conservation, and rural vitality (Schoeneberger et al. 2016).

Across the Northern Plains, trees and forests are valued for the many services they provide in support of livelihoods, soil and crop protection, lowering cold and heat stress on livestock, streambank protection, wildlife habitat, water storage, wood production, carbon sequestration, recreation opportunities, and esthetic values (Vose et al. 2012, Schoeneberger et al. 2016). These services have been and continue to be at risk from climate-related hazards (Kunkel et al. 2013) and disturbances, such as wildfire and insects (Westerling et al. 2014, Negrón and Fettig 2014). Risks associated with climate change result from the dynamic interactions among human communities, ecosystems, and the hazards arising from a changing climate (Oppenheimer et al. 2014). While location, such as a floodplain, influences exposure to climate-related hazards, risk to these services is not determined by exposure alone. People, plant, and animal species have varying capacities to adapt and survive perturbations associated with these hazards (Briske et al. 2015). The goal of this paper is to identify the key risks over the next 50 years from both natural and anthropogenic climate change to native and agricultural forests across the Northern Plains. We also identify potential adaptation and mitigation strategies to sustain the ecosystem services these systems currently provide and could provide under a changing climate.

2 Hazards, exposure, vulnerability, and key risks

Risk of climate change impacts results from the interaction of hazard, exposure, and vulnerability (Fig. 1). State forest assessments within the Northern Plains identified existing hazards of wildfire, insects and disease, and invasive species as a challenge to forests (CSFS 2010; DNRC 2010; Kotchman 2010; WSFD 2010; SDDA 2010; Nebraska Forest Service 2015). These existing hazards are influenced by the natural variability of climate and, in the future, will be affected by climate change. The degree of vulnerability and exposure to climate-related hazards is influenced by fluctuating socioeconomic conditions, management actions, and governance (Oppenheimer et al. 2014). For example, land use regulations may limit development in the wildland-urban interface, possibly reducing wildfire risk (Liu et al. 2015).

2.1 Hazards—climate and disturbances

Climate-related hazards in the Northern Plains have included drought, convective storms, extreme wind events, snow storms, floods, heat waves, and cold waves (Kunkel et al. 2013). Hazards associated with projected climate change include the continued trend of warming temperatures, increases in evaporative demand, changes in precipitation, increases in severe weather events, changes in the frequency and intensity of disturbances such as wildfire, outbreaks of insects and diseases, and increased presence of invasive species (Table 1). Annual 5-day maximum temperatures are projected to increase 3.3–4.4 °C

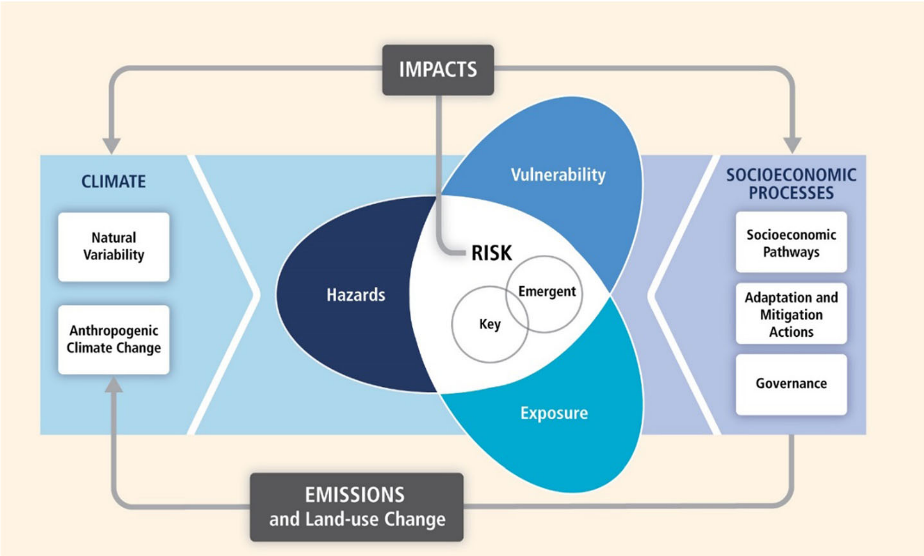

Fig. 1 Schematic of the interaction among the physical climate system, exposure, and vulnerability to produce risk. Risk of climate-related impacts results from the interaction of climate-related hazards (including hazardous events and trends) with the vulnerability and exposure of human and natural systems. Vulnerability and exposure are largely the result of socioeconomic pathways and societal conditions (although changing hazard patterns also play a role). Changes in both the climate system (left side) and socioeconomic processes (right side) are central drivers of the different core components (vulnerability, exposure, and hazards) that constitute risk (Oppenheimer et al. 2014; Fig. 19.1)

across the Northern Plains by 2050 relative to the reference period of 1976–2005 (Pierce et al. 2014, 2015). Warming is projected to continue through 2085 with projected increases greater than 5 °C south of the South Dakota/Nebraska border and increases of nearly 7 °C further north. The number of days with maximum temperature exceeding 35 °C increases by 20–40 days across the region by 2050. Precipitation is projected to change, in amount and intensity. For the vast majority of the region, rainfall events of 5.1 cm or more are expected to increase by 100% by 2050. Maximum precipitation amounts received within a 24-h period are projected to increase 10–30% by 2050 and 15–40% by 2085.

Under changes in temperature and precipitation, subalpine forests are projected to decline in extent and montane forests to expand (Hansen and Phillips 2015; Mathys et al. 2016). When atmospheric carbon dioxide is included as a growth factor in the modeling of tree growth, tree cover at the highest elevations in the Colorado Rockies did not decline but vegetation carbon did (Notaro et al. 2012). Positive effects of growth in native forests with longer growing seasons and warmer temperatures are lessened with increasing plant water stress as the growing season lengthens (Hu et al. 2010). Native forest responses to wildfires, diseases, and beetle attacks may offset or exacerbate projected climate change effects on native forests. Understanding these interactions is critical to developing management strategies that reduce exposure (Loehman et al. 2016). For example, King et al. (2013) reported that changes in fire frequency, as affected by climate and/or human intervention, may be more important than the direct effects of climate change in determining future distributions of ponderosa pine (*Pinus ponderosa*) in the Black Hills.

Table 1 Hazards associated with projected climate change and related vulnerability of native forests and agricultural forests (from Schoeneberger et al. 2016; Vose et al. 2012, 2016)

Hazard	Vulnerability
Longer, hotter growing seasons with earlier arrival of spring; declining snowpack	Increased plant-water stress
	Greater susceptibility to pests and diseases
	Reduced tree growth, function, and survival
	Reduced nursery operations for production of agroforestry plant materials
	Increased erratic seed/cone development and seedling establishment; greater seedling mortality
Warmer winter temperatures	Increased winter desiccation
	Increased chance of frost damage
	Inadequate winter chilling requirements for flowering and seed germination
	Greater susceptibility to insect pests due to reduced cold-associated mortality
More extreme weather events (e.g., downpours, droughts, snowstorms, temperature extremes)	Increased flooding damage and root mortality
	Increased ice damage
	Greater susceptibility to pests and diseases
	Reduced tree growth, function, and survival
Greater wildfire risk from warmer and expected drier summers	Reduced tree growth, function, and survival
	Loss of trees/species from landscapes
More outbreaks of tree pests and pathogens	Reduced tree growth, function, and survival
	Loss of trees/species from landscapes
Increased dominance of invasive species	Reduced tree growth, function, and survival
	Loss of trees/species from landscapes

Over the last three decades, a warming trend across western USA has coincided with an increase in the frequency of large (> 400 ha) forest fires and area burned (Westerling et al. 2014). Wildfires in mid-elevation native forests in the northern Rockies account for 60% of the increase since 1970. These wildfires have been particularly affected by earlier spring snowmelt and longer summer dry seasons, whereas, moisture availability has buffered higher elevation forests. In the near term, frequency and extent of wildfire is likely to increase (Westerling et al. 2014). While increasing air temperatures are projected, precipitation projections are highly uncertain in the Colorado Rockies, thus, projections for fire activity are mixed. Overall, increases in wildfire activity can be expected to vary across the Northern Plains because of the complex interaction among weather patterns, topography, tree species distribution, and species adaptation to past fire regimes (Kolb 2013).

As with climate and wildfire, recent relationships between insect outbreaks and warmer and drier climates have been documented for various bark beetle species (*Dendroctonus* spp) (Bentz et al. 2010). Widespread burning, prior extensive harvest, and recent fire suppression have resulted in landscapes of trees at ages known to be susceptible to bark beetle outbreaks (Negrón and Fettig 2014). Epidemic mountain pine beetle (*Dendroctonus ponderosae*) populations have affected over 600,000 ha of forests in Colorado, Wyoming, Nebraska, and South Dakota (Harris 2014) and more than 1.6 million ha across Montana (Hayes 2015). Future insect outbreaks are projected to cause tree mortality at elevations higher than have occurred to date, with increased temporal and spatial variability (Bentz et al. 2010).

Our understanding of hazard-facing agroforestry tree species under climate change is currently limited. Pests and diseases, however, will be an increasingly significant challenge as many agroforestry species used in the Northern Plains are introduced species that then face extreme conditions and pests different from their place of origin. Many tree improvement efforts, established in 1953 in the Great Plains, were eliminated in the mid-1990s, despite emerging pest and disease concerns. The use of Scotch pine (*Pinus sylvestris*) and other pine species historically planted throughout the Plains is declining due to increasing spread and mortality from pine wilt (*Bursaphelenchus xylophilus*). Ash (*Fraxinus* spp.), another key species in the Northern Plains, has also been removed from many planting lists because of the eminent invasion of emerald ash borer (*Agrilus planipennis*). This highly destructive pest has recently been detected in Colorado and Nebraska (USDA APHIS 2017).

2.2 Exposure and vulnerability

Past exposures to climate-related hazards can result in adjustments by plants, animals, and humans that reduce susceptibility and vulnerability to the repeated disturbance. For example, bark characteristics of ponderosa pine allow it to survive low-intensity surface fire. In response to the 1930s Dust Bowl, over 29,000 km of windbreaks were planted to protect soils and crops between 1935 and 1942 (Williams 2005); these windbreaks still play key roles in creating diversified production systems (USDA 2015). Consequently, the degree to which native and agricultural forests are vulnerable to the hazards identified in Table 1 is influenced by the long-term exposure to such hazards as well as management actions taken to reduce vulnerability.

Climate change is likely to exacerbate the impacts of past stressors as well as provide new stressors on forests and the associated communities (Fig. 1). Across the Great Plains, the total area burned by large wildfires has increased to 400% over the 1985–1994 period to the 2005–2014 period; projected increases in wildfire activity could further strain local fire departments, particularly volunteer departments and those in the northern Great Plains (Donovan et al. 2017). Commodity prices, varying demands for particular crops, and changes in technology such as larger farming equipment can be incentives to remove agroforestry plantings, thus, increasing crop exposure to severe weather (Kotchman 2010; Nebraska Forest Service 2015). For example, comparison of 2012 to 2009 aerial imagery of tree cover in Nebraska documented pivot irrigation expansion with concomitant windbreak and other tree removal (personal communication, D. Meneguzzo, US Forest Service). While not irreversible, this loss of soil and crop protection results in a set of conditions that can increase the susceptibility of crops and agricultural communities to economic losses under changing climate conditions.

Over 80% of private forestland in the Northern Plains is held by family and individual owners (Butler et al. 2016) and in parts of the region, this land base serves as a major source of material for the wood products industry. State forest assessments identified the challenge of maintaining a viable forest industry and forest products market. Structural changes in the forest industry and disruption of forest-based operations associated with wildfire have led to diminished workforces in some areas and instability in local forest industries (Keegan et al. 2004; Vaughan and Mackes 2015). Further, international and national forces such as globalization, declining demands for paper, and industrial restructuring of US forest sector combine with local dynamics to influence the extent of forest management, the availability of a skilled workforce, and economic incentives for forest management at state and local levels (DNRC 2010; Keegan et al. 2011). These local, regional, and global changes result in a set of conditions that increase the susceptibility and vulnerability of forests and forest-dependent communities to climate-related disturbances and potential economic losses.

2.3 Key risks

Key risks are identified as those risks where climate hazards are persistent; exposure to such hazards could result in irreversible changes, and human communities are dependent upon the services of native and agricultural forests (Oppenheimer et al. 2014). These forests within the Northern Plains are currently and will continue to be exposed to climate stressors and the related disturbances of wildfire, insects, disease, and invasive species. Loss of native and agricultural forests and the associated socioeconomic effects could result in large impacts to human communities dependent upon these resources. We identify four key risks as related to losses when vulnerabilities are not addressed: (1) loss of protection of crop, livestock, and soils associated with agroforestry practices, (2) loss of rural livelihoods and agricultural-related and forest-based income, (3) heightened risk of damage and loss to human life, property, and source water for domestic and agriculture uses, and (4) reduction of forest ecosystems, biodiversity, and the ecosystem goods, functions, and services they provide for human livelihood.

Protection of crop, livestock, and soils, as well as agricultural-related income will be at risk. Success of agroforestry and other agricultural forest resources in supporting productive and resilient landscapes is dependent on these resources being in place and in good condition when these services are needed. Agroforestry practices include field, farmstead, and livestock windbreaks; riparian forest buffers; silvopasture systems; alley cropping;

and forest farming (Schoeneberger et al. 2016; see Supplementary Table 1). Decisions to proactively adopt and retain agroforestry plantings are human-dimension dominated and involve overcoming barriers related to cost, labor, complexity of practice and management, uncertainty of land tenure, and lack of information (MacFarland et al. 2017). Maintaining the condition of plantings involves the susceptibility of plant materials to weather extremes and projected climate change effects (exposure), in addition to management actions (Dosskey et al. 2017).

Ecosystem services such as watershed protection, biodiversity, forest products, and cultural benefits will be at risk in native forests. Assisting forests to retain healthy and resilient attributes against the potential of extreme and variable climatic events requires owners and managers to carefully analyze forested landscapes (inventory), consider multiple management practices, and implement those practices in a timely manner as both proactive and reactive responses to changing conditions (Hessburg et al. 2015, Stephens et al. 2012, see Supplementary Table 2). For example, the Montana State University Extension Forest Stewardship program (http://www.msuextension.org/forestry/stewardship.htm) has helped more than 3500 landowners conduct inventories and develop management plans on over 600,000 ha. In this way, landowners are more likely to implement practices that help them achieve their objectives, as well as respond in a thoughtful and timely manner to climate-related hazards. As with agricultural forests, active management is influenced by ecological as well as social and economic factors, such as landowner objectives, availability of a skilled workforce, and treatment costs.

3 Risk management—adaptation of Northern Plains forests

Developing strategies to address risks to native and agricultural forests in the Northern Plains can be fraught with uncertainty, complexity, and controversy. While gradual trends in climate are likely, changes in the frequency and intensity of extreme events are also projected. Management strategies that achieve multiple objectives over a range of future conditions may help address uncertainty. Decisions to implement silvicultural or agroforestry practices may enhance future resilience to drought, insect, and wildfire in native or agricultural forests, thereby reducing risk (Vose et al. 2016; Dosskey et al. 2017). Further, the integration of adaptation and mitigation strategies can generate mutual benefits, such as crop protection and carbon sequestration from planted windbreaks. Native and agricultural forests are also a viable option for providing adaptation services, potentially addressing other objectives such as reducing threats to water and soil resources and facilitating species movement to more favorable conditions. As climate continues to change, retaining existing native and agricultural forests may be challenging, necessitating a new and different approach. We briefly review adaptation options available for native and agricultural forests (for greater detail, Dosskey et al. 2017; Schoeneberger et al. 2017a; Vose et al. 2012, 2016).

3.1 Agroforestry adaptation

Reducing ecological, economic, and social risks to agroforestry practices under projected climate change will be a key in maintaining and improving these practices. Vulnerability of agroforestry tree resources translates to a loss of ecosystem services that can lead to increased vulnerability of agricultural production and natural resources. Because agricultural forests are planted systems, the primary approaches for reducing risks are through design, plant selection, and management (Table 2). General adaptation strategies include the following:

- Design practices to be multi-functional (serve more than one management need) to encourage adoption and long-term retention by producers.
- Modify designs to accommodate new and future production methods and equipment.
- Plant diverse species/cultivars to increase options available for the uncertain conditions associated with projected climate changes.
- Select woody species that will be better adapted to the future climate recognizing that woody plants may be expected to live 60 years or more.
- Promote the development of plant cultivars with better resistance/resilience to stressors.
- Use seed from locations currently under conditions that are similar to those expected locally under climate change.
- Use tree care practices (pruning, weed, and pest control) to maintain tree health and practice performance.

Table 2 Agricultural and native forest functions that support climate change adaptation (from Schoeneberger et al. 2017a, Millar et al. 2012; Keane et al. in press). Adaptation is defined as action to reduce or eliminate the negative effects of climate change or take advantage of the positive effects

Major climate change functions	Agroforestry	Native forests
Reduce impacts of climate-related hazards	• Alter microclimate to reduce impact of extreme weather events on crop production • Alter microclimate to reduce livestock stress • Alter microclimate to maintain quality and quantity of forage production • Provide greater structural and functional diversity to maintain and protect natural resource services	• Promote disturbance-resilient species, appropriate for site conditions, such as ponderosa pine on dry sites, Douglas fir on extremely dry sites • Reduce moisture stress by reducing forest density through thinning, prescribed fire, wildfire use, domestic animals such as goats • Manage for landscape heterogeneity (age class, structural diversity, species type) to lower large-scale fire risk and insect outbreaks
Enhance resilience	• Provide greater habitat diversity to support organisms (e.g., native pollinators, beneficial insects) • Create diversified production opportunities to reduce risk under fluctuating climate	• Promote genetic diversity and regeneration in species currently stressed by disease (e.g., white pine blister rust) through prescribed fire and/or silvicultural treatments • Manage herbivory • Promote regeneration through seed collection and planting for species under current stress (e.g., disease, disjunct populations)
Actively facilitate plant species movement	• Assist in plant species migration through agroforestry planting decisions	• Plant potential microsites with mix of species
Allow animal species to migrate to more favorable conditions	• Provide travel corridors for species migration with agroforestry plantings	• Provide travel corridors for species migration
Maintain or create refugia		• Identify forests less likely to be affected by climate change; manage as refugia for plant and animal species

3.2 Forest adaptation

Reducing ecological, economic, and social risks to forests under projected climate change will be a key in enhancing resilience and maintaining forest health. Through current mutualistic relationships between forest land owners and the local wood products industry, landowners are able to effectively manage their forests with income derived from selling trees. Where such relationships are weak or do not exist, societal benefits may arise from building and maintaining a local workforce to reduce wildfire risk, enhance landscape resilience, and engage in wildfire response (Huber-Stearns et al. 2016). For example, the Coalition for the Upper South Platte has developed and maintained local capacity for wildfire response and post-fire rehabilitation on public lands, as well as risk mitigation and forest restoration on private lands by partnering with government, non-profit, and private organizations to leverage funding, share resources and expertise, and recruit and develop local community leaders.

The diversity of forest ecosystems and ownerships across the Northern Plains requires careful consideration of site characteristics currently and likely conditions in the future. An adaptive management strategy, designed to be responsive to changing environmental conditions, would ensure ecosystem resilience under the changing conditions. Multiple integrated approaches will be important to support climate change adaptation (Table 2). General adaptation strategies for forest management in the Northern Plains include the following:

- Maintain forest resistance to current climate-related hazards and disturbances
- Evaluate and if necessary, modify forest practices (winter harvest, best management practices) that maintain soil quality and nutrient stocks under seasonal changes in climate.
- Design harvest infrastructure (roads, buffer zones) to prevent potential increased flooding and landslides under greater precipitation intensity.
- Enhance drought resilience in forests at risk of extreme water stress: (a) shallow soils, (b) dense stands, (c) drought intolerant species combinations, and (d) older age distributions.
- Protect and enhance genetic diversity of tree species through in situ and ex situ conservation.
- Promote landscape diversity (tree species, age class distribution, structural diversity, patch sizes) through combinations of silvicultural practices.

3.3 Transformational management options

As climate continues to change, it may not be feasible to retain the existing plant and animal species on specific sites within the Northern Plains landscapes and a reconfiguration may be necessary (Millar et al. 2007). Native and agricultural forests may require innovative practices ranging from stand-replacing species conversion to bioengineering of species better adapted to projected conditions (Dumroese et al. 2015). Assisted migration, the intentional movement of species to more climatically suitable locations, may be a viable option (Williams and Dumroese 2013). Agroforestry, through intentional tree plantings on the landscape, may offer a way to facilitate assisted migration of plant species (Dawson et al. 2011), as well as enhance faunal migration within highly fragmented agricultural lands (Krosby et al. 2010). Assisted adaptation, where existing genetic diversity within regional populations is used to identify and propagate high-performing individuals within each species, could be valuable in native forests (Kolb 2016). Knowledge synthesis is needed to understand risks associated with transformational options and monitoring will be critical to determine outcomes.

4 Mitigation—native and agricultural forests as a climate change tool

Native and agricultural forests are a viable option for providing mitigation services, such as sequestering carbon and reducing greenhouse gas (GHG) emissions (Table 3). Native forests can promote carbon sequestration in woody biomass and soils (Vose et al. 2012). In the Northern Plains, forests and harvested wood products sequestered 15.7 Tg CO2 eq. per year in 2013 (USDA 2016). Wood used as construction material serves as long-term carbon storage, increasing the carbon capture capacity of a forest. There are, however, caveats to maximize this form of carbon storage. Transportation in the harvesting and manufacturing process accounts for approximately 90% of the fossil fuel use; thus, utilizing local forest materials and locally milling for local building significantly reduces these emissions. Utilizing wood waste material for energy production also decreases fossil fuel emissions as well as industry energy requirements. Becker et al. (2011) noted that supply guarantees, industry presence, transportation to processing centers, and the value of biomass were limiting factors to biomass energy development while agency budget, staffing, environmental concerns, and partnership aggravated the problem rather than impeded progress.

Like native forests, agroforestry has the ability to sequester large amounts of carbon especially for the small amount of land area occupied by these practices (Table 3) (Schoeneberger et al. 2017b). Carbon storage (aboveground and belowground) rates in North and South Dakota, Nebraska, and Kansas have been estimated to be around 3 Mg C ha^{-1} for deciduous and conifer windbreaks (Possu et al. 2016), which is greater than agricultural

Table 3 Agroforestry and native forest functions that support climate change mitigation (from Schoeneberger et al. 2017a, Vose et al. 2012). Mitigation is defined as activities that reduce GHGs in the atmosphere or enhance the storage of GHGs stored in ecosystems

Major climate change functions	Agroforestry functions	Native forests
Sequester carbon	• Accumulate C in woody biomass. • Accumulate C in soil	• Accumulate C in woody biomass • Accumulate C in soil
Reduce GHG emissions	• Reduce fossil fuel consumption: By reduced equipment runs in areas with trees By reduced farmstead heating and cooling • Reduce N_2O emissions: By greater nutrient uptake through plant diversity By reduced N fertilizer application in tree component • Enhance forage quality thereby reducing CH_4	• Reduce CO_2 emissions from transportation in harvesting and manufacturing processes by utilizing local forest materials and locally milling for local building • Utilize wood waste material for energy production • Where feasible, use harvest for biochar development

management activities, such as conservation tillage. In terms of relative contribution within a field, inclusion of a windbreak (comprising 3–5% of a field) for purposes other than mitigation services, can potentially almost double the total carbon sequestered from converting a field from conventional to no-till after 50 years (Schoeneberger 2009). Indirect carbon and other greenhouse gas contributions from agroforestry, such as emission avoidance in fields and energy savings from farmstead windbreaks, may be even greater than that from carbon sequestration (Ballesteros-Possu et al. 2017). The use of agroforestry as small land area plantings within the large Northern Plains agricultural land base represents a viable and important strategy for sequestering large amounts of new carbon in this region.

5 Collaboration in forests at risk

The forested landscape in the Northern Plains, as with most of the western United States, is highly variable; restoring, maintaining, or increasing the resilience of these forests will require local and landscape approaches (Hessburg et al. 2015). The effects of projected climate change are experienced by many entities—public land managers, family forest owners, forest industry, livestock producers, private landowners living in the wildland urban interface, and rural communities dependent on forest-based economies. No single entity has the capability to sufficiently address these effects; risks cross ownership boundaries. Controversy can surround strategies developed to address these risks. What actions should be taken? Where and at what spatial/temporal scale should actions occur? What are potential unintended and undesired consequences? "Place-based" collaborative efforts have emerged to work through these challenges for native forests; lessons learned from these efforts can also benefit adaptive management (Cheng and Sturtevant 2012).

5.1 Attributes of successful collaborative management

Collaboration occurs when two or more parties voluntarily pool their assets (human, financial, knowledge, technical) to achieve goals they could not attain working alone. In forestry contexts, collaboration, to date, has primarily emerged in response to widely agreed-upon threats, predominantly wildfire.

Several attributes common across collaborative efforts include the following:

- Supportive higher-level policies and commitment of resources: Large, high-profile wildfires across the western USA led national-level policy-makers to establish the policy foundation for collaborative approaches in an attempt to reduce wildland fire risks for local/rural communities and the environment. This policy foundation includes an "all lands" approach that acknowledges the critical role of state and local governments, communities, and private landowners in sharing the burden of reducing wildfire risk across the landscape. These policies have benefited by funding appropriations from federal and state governments.
- Facilitative and risk-taking leadership across authorities: Leaders of public and private organizations can energize the collaborative process when they use their positions to provide a vision and then, direct human, financial, and technical resources from their respective organizations towards collaborative outcomes. One example is the Front Range Roundtable in Colorado. Leaders from federal, state and local governments,

non-governmental organizations, and research institutions leveraged their own organization's assets to develop a collaborative program of work across land ownerships and jurisdictions. This effort culminated in a large-scale restoration project across federal and non-federal lands, the Colorado Front Range Collaborative Forest Landscape Restoration Project (CFLRP) (Cheng et al. 2015).

- Boundary spanners: These individuals and organizations address the complexity of risk, knowledge gaps, and work to ensure cross-organizational communication and collaboration. The Blackfoot Challenge in northwestern Montana is composed of private landowners, federal and state land managers, local government officials, and corporate landowners who reach across their ownership and jurisdictional boundaries to address pressing natural resource issues in the Blackfoot River watershed, with pro-active drought response as a keystone issue (Weber 2009).
- Collaborative capacity: Participating organizations may pool financial resources across government and non-government organizations to engage a third-party facilitator (Cheng 2006). This facilitator takes on tasks that ensure a continuity of operational capacity.
- Focus on frequent communication, shared learning, and trust-building: The working business of collaboration is based on regular face-to-face communication, with an orientation towards shared learning and trust-building. Collaboration works best when participants come with an attitude that they each possess valuable knowledge and understanding and are open to different ways of knowing (Daniels and Walker 2001).
- Producing tangible results: To balance the costs of collaboration, participants need to realize tangible benefits and outcomes. Starting with demonstration projects can help build trust and confidence for larger scale activities. Producing on-the-ground results can also attract attention from funders and other potential participants that collaboration is a good investment (Ansell and Gash 2008).
- Investment in effects monitoring and adaptive management: Managing forests to reduce the vulnerability, and increase resilience, to climate-induced disturbances is a long-term proposition. Collaborative groups are increasingly recognizing the critical importance of effects monitoring to inform ongoing adaptive management. The CFLRP is innovative in that it mandates a multi-party monitoring strategy for funded projects; approximately 10% of annual expenditures are dedicated towards ecological and socio-economic monitoring. Thus far, a substantial dataset has been compiled and recent analysis has documented progress towards several treatment objectives (Briggs et al. 2017). The dataset serves as a critical baseline to gauge the long-term effects of the project.

5.2 Pressing challenges for collaborative efforts

Collaboration in forest management faces numerous challenges. Sustaining investments in long-term monitoring of projects is a challenge, and yet, important in order to determine if the collaborative efforts achieved the desired results. Problems of participant turnover and maintaining collaborative capacity compound the sustainability of collaboration overtime. National-level policies and funding supporting collaborative approaches to address climate-induced vulnerabilities remain limited. Long-term on-the-ground programs allow for monitoring of adaptation strategies to close the uncertainty gap between the effects of ongoing forest management actions and future disturbances on long-term forest resilience.

6 Conclusions

Climate change will exacerbate current hazards and as well as influence new hazards in the Northern Plains. Under climate change, native and agricultural forest resources will be exposed to warmer temperatures, longer growing seasons, altered wildfire regimes, and insect, disease, and pest outbreaks. While location can influence exposure to these hazards, risk must be evaluated with the knowledge that people, species, and ecosystems have varying capacities to adapt and survive these hazards. Management has been an important component in supporting productive and resilient landscapes in the Northern Plains. Success of adaptation and mitigation strategies for native and agricultural forests is dependent upon proactive management; implementation of this proactive management is dependent, not only on increasing understanding of potential ecological impacts but also addressing social and economic factors that dissuade or forestall management. Place-based collaborative efforts offer ways to address landscape challenges and enhance social learning on successful adaptive management practices.

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Compliance with ethical standards

Conflict of interest The other authors declare that they have no conflict of interest.

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